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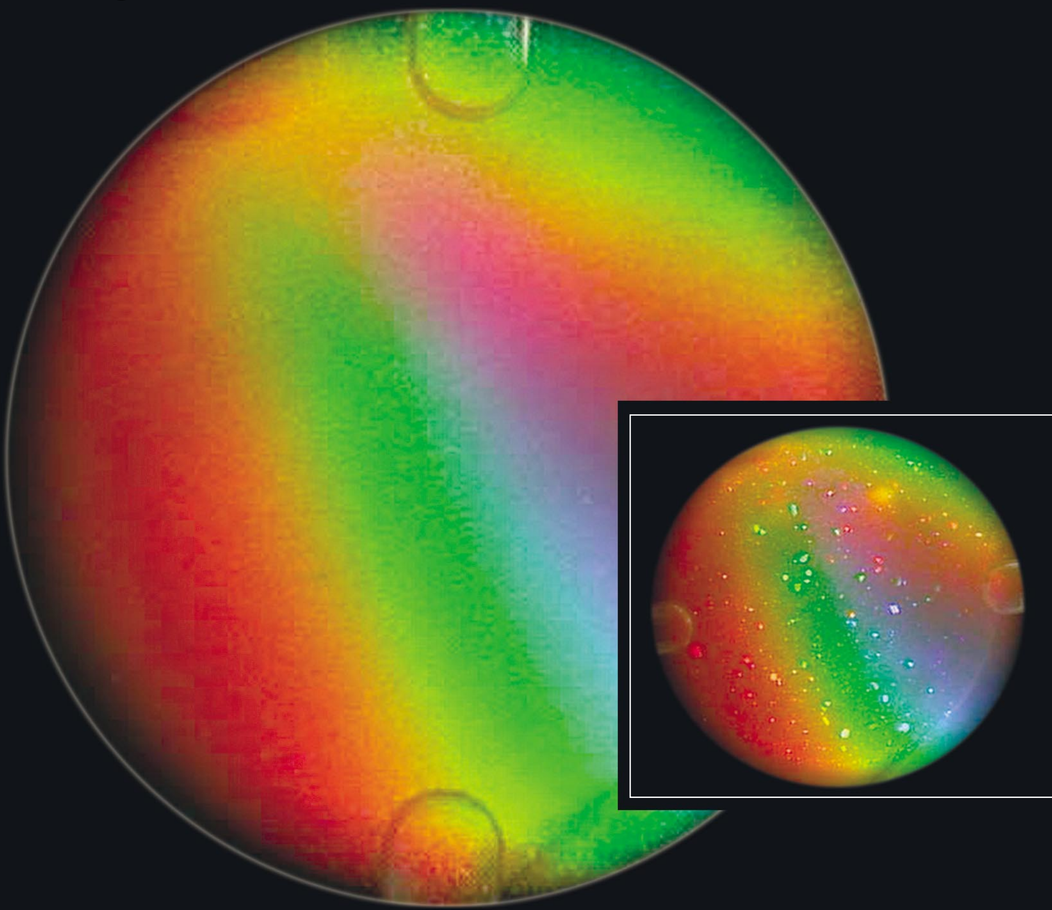
Space Research

Office of Biological and Physical Research

March 2003, Vol. 2 No. 2

Setting New Research Priorities



Profile: Joseph Santner

National Aeronautics and Space Administration

Letter From the Associate Administrator

As I reflect on the inspiration that the fallen crew of Space Shuttle *Columbia* embodies for millions of people around the world, I believe Administrator Sean O'Keefe captured it well when he said, "They gave their lives for something they believed in completely: the peaceful pursuit of discovery." Like the research community they were supporting, the crew was wonderfully diverse in background and culture and readily joined together in this pursuit. Reflecting the best in the human spirit, the crew sought to advance human exploration of space and create new knowledge to help solve problems that face all of us on Earth every day — from pollution to limited energy resources to cancer and myriad other diseases.

As our researchers, administrators, and support staff continue with our own contributions to the pursuit of discovery, for which these seven dedicated astronauts made the ultimate sacrifice, we are entrusted with the responsibility of making the most of the passion, knowledge, and funding that we have to work with. Toward this end — and in support of NASA's mission "to understand and protect our home planet, to explore the universe and search for life, and to inspire the next generation of explorers" — we are developing a more comprehensive strategy to guide and prioritize all research and other activities throughout the Office of Biological and Physical Research (OBPR).

This enterprise strategy comprises several elements. It includes points from the 10-year OBPR research plan that was recently developed, "roadmaps" toward answers to five strategic questions set forth in the research plan, and input from the OBPR research community, OBPR staff, and previous committee reports.

The 10-year research plan fits into the 25-year strategic plan for NASA and its exploration team to discover life's limits in our universe. Our plan was designed to maximize our invaluable but limited resources for the hundreds of research projects funded by OBPR. Here are a few highlights from the plan:

- We will focus efforts to address a clearly articulated set of organizing questions.
- We will support three major research thrusts: strategic (to enable NASA's mission to explore the universe and search for life); fundamental (to address the role of gravity in biological and physical processes); and industrial partnerships (to facilitate applied research of industrial significance).
- We will use efficient management and appropriate processes to measure technical and management performance, research outcomes, and impact.
- We will initiate OBPR Explorer Missions, patterned after the Office of Space Science Explorers Program, with regular opportunities for research on free-flying spacecraft.
- We will develop a stronger, more diverse investigator community.

The first item on the list refers to organizing questions. Five questions are the basis for the roadmaps that our research divisions and public and educational outreach staff are formulating: (1) How can we assure survival of humans traveling far from Earth? (2) What must we know about how space changes life forms so that humankind will flourish? (3) What new opportunities can our research bring to expand understanding of the laws of nature and enrich lives on Earth? (4) What technology must we create to enable the next explorers to go beyond where we have been? (5) How can we educate and inspire the next generations to take the journey?

The teams mapping paths toward answering these questions are gathering input from their own divisions and other divisions within OBPR, and they are incorporating information from previous committee reports. Their goals are to determine a research strategy for each question, the platforms or programs to execute the science, applications for the research, and the means to measure progress on answering each question.

As we work toward fulfilling our 10-year plan, we will continue to be an integral component of NASA's vision to improve life here, to extend life to there, and to find life beyond. As we fill our unique role here at NASA more completely, we will be helping not only our scientific, educational, and industrial partners and ourselves, but also the American citizens and international populations we serve.

Mary E. Kicza

Mary Kicza
Associate Administrator
Office of Biological and Physical Research

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On the cover:
The Office of Biological and Physical Research is setting new priorities for research, such as the Physics of Colloids in Space experiment, an investigation of colloidal systems (fine particles suspended in a fluid). Crystals grown in Earth's gravity (inset) join together to form relatively large and poorly formed poly-crystals. Crystals grown in microgravity (main image) are homogeneous, high-quality aggregates. They have many potential uses in industry, communications, and medicine. credit: NASA

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OBPR Awards Research Grants

Seventeen scientists have been selected by the Office of Biological and Physical Research (OBPR) to receive grants to conduct advanced human support technology research — research to help keep astronauts safe and healthy while they are traveling in space.

The grants, which were awarded for periods of one to three years, are worth up to $8.8 million over three years. Six grants cover research on technologies for advanced environmental monitoring of space habitats. One grant covers research on advanced control systems. Two grants are for research that addresses advanced food technologies, and two are for research on advanced technologies for extravehicular activity (work done outside the International Space Station or a space shuttle while it is in orbit). The remaining six grants include novel approaches to waste processing, including air revitalization, water recycling, thermal control, and treatment of solid wastes.

These technologies not only could have a significant effect on safely conducting space travel in low Earth orbit and beyond, they could also improve environmental technologies and quality of life on Earth.

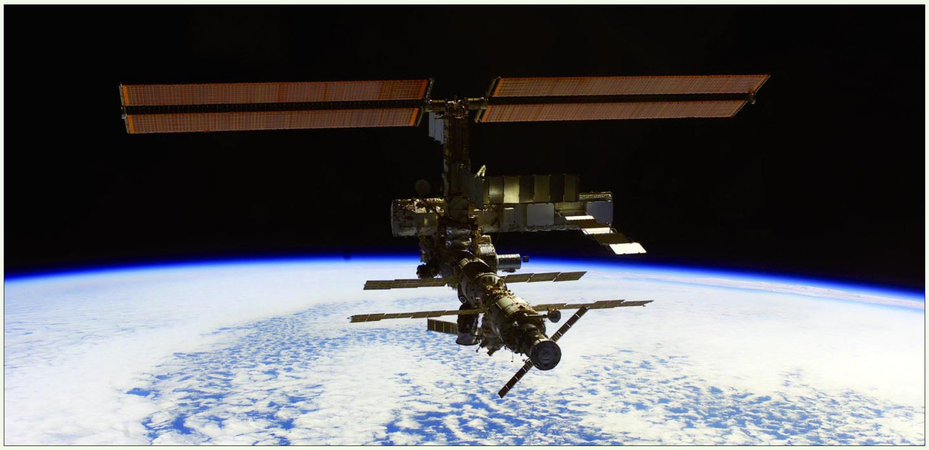
The grant awardees were selected from 113 proposals received in response to the research solicitation released in March 2002. Proposals were peer-reviewed by scientific and technical experts from government, academia, and industry.

For a list of grant recipients, visit *http://spaceresearch.nasa.gov/general_info/OBPR-02-227.html*.

credit: NASA

Advanced human support technology research funded by grants from the Office of Biological and Physical Research will help to make living and working in space safer for astronauts like Expedition 6 Commander Ken Bowersox, pictured here conducting an experiment aboard the International Space Station.

Space Station Action Plan



credit: NASA

Leaders of the five space agencies that are partners in the International Space Station (ISS) unanimously agreed to the framework for a technical option that will allow expansion of the scientific program on the station, including an increase in the number of permanent crewmembers on the ISS. This expansion is part of their agreement to maximize station utilization in the 2006–2007 timeframe through greater use of ISS research elements.

The heads of agencies of the partners (Canada, Europe, Japan, Russia, and the United States) met in Tokyo in December 2002 to conclude the work that was agreed to in the 2002 Program Action Plan. The 2002 Program Action Plan was adopted at the heads of agency meeting in Paris in June 2002; it provided a process and schedule during the six months from June through December 2002 to develop an option path to meet ISS research requirements.

The agency heads noted that ISS construction is proceeding according to plan. They agreed on a process for selecting a space station configuration that will meet the enhanced capabilities of the agreed-to option. The process will include technical and programmatic assessment, cost estimation, and internal budgetary reviews by each partner.

The partners agreed to two meetings of the heads of agencies over the next year as the space station configuration and associated agreements are developed — a meeting in Moscow in summer 2003 and a meeting in Washington, D.C., in winter 2003.

STS-107 Letter

credit: NASA

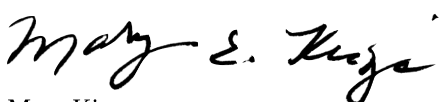
From left to right: David Brown, Rick Husband, Laurel Clark, Kalpana Chawla, Michael Anderson, William McCool, Ilan Ramon.

To our research community directly involved with STS-107:

The crew of the *Columbia* knew — as everyone in NASA knows — that space research offers something never before achievable in the history of humankind: a glimpse of what our life, what nature itself, is like in a world without the effects of gravity. The crew also knew that people like themselves must be directly involved, because the very character of research begins with the ability to observe, to be able to recognize something new and valuable, and then to endeavor in a new direction that so often cannot be anticipated or preprogrammed into a machine.

The crewmembers were thrilled with what they were doing. They put in extra time and effort to make sure the research would be successful. With you, they overcame just about every hurdle that faced the payloads' operations during this mission. Now, with you, *our* first obligation is to continue to support the investigation team that is to determine the cause of this tragedy. We will follow their lead in setting up an orderly process to collect, review, and ascertain every aspect of the payloads, their operations, and their condition during reentry. We know you will support us in that obligation.

The renowned physicist Freeman Dyson once said, "The American space program is at its most creative when it is a human adventure." In this context, he went on to say that science is much more than just space and that space is much more than just science. We couldn't agree more. Human spaceflight is also technology, education, human health, and industrial entrepreneurship, and it deepens the world in so many ways. Like the crews before and those to come, the people of the STS-107 did more than just science. They had and continue to have a higher calling. They inspire our lives.



Mary Kicza
Associate Administrator, Office of Biological and Physical Research

Meet the Expedition 6 ISS Science Officer

credit: NASA

Donald Pettit

Donald Pettit, a scientist with the Los Alamos National Laboratory in Los Alamos, New Mexico, recently completed his duties as the Expedition 6 International Space Station (ISS) science officer.

Pettit assumed the role of overseeing the life and physical sciences research being conducted on the ISS after he and the other Expedition 6 crewmembers flew there aboard Space Shuttle *Endeavour* — Pettit's first flight into low Earth orbit — and took over from the Expedition 5 crew in November 2002. While aboard the ISS, Pettit was responsible for ensuring that the on-board scientific experiments were conducted and that the data obtained from those experiments were made available to the principal investigators involved. Because the station is still under construction, Pettit also performed a number of station maintenance and repair duties. In this latter capacity, Pettit had another first when he replaced his Russian crewmate Nikolai Budarin for a spacewalk with Commander Kenneth Bowersox to work on a girder that was attached to the station when the Expedition 6 crew arrived.

Pettit received a doctorate in chemical engineering from the University of Arizona in Tucson in 1983. From 1984 until 1996, when he was selected for the astronaut corps, Pettit was a staff scientist at Los Alamos National Laboratory. During his tenure at Los Alamos, Pettit had his first experience with reduced gravity while performing experiments aboard NASA's KC-135. He also assisted with the development of Mars exploration technology.

In 1998, after completing two years of astronaut training, Pettit was assigned to the Astronaut Office Computer Support Branch. He was chosen to begin training as a backup Expedition 6 crewmember in 2001. He served as science officer for the time that the Expedition 6 crew remained on the ISS.

For more information, see the Don Pettit Space Chronicles at *http://spaceflight.nasa.gov/station/crew/exp6/spacechronicles.html*.

Setting New Research Priorities

The Office of Biological and Physical Research is developing a comprehensive research plan around five organizing questions to propel NASA into the next realm of exploration.

When the construction of the International Space Station (ISS) is completed, the station will be an orbiting laboratory fully dedicated to scientific and engineering research. Given limitations on resources, what scientific research is vital to take full advantage of this unique long-term microgravity facility, as well as other spacecraft and research facilities on the ground, to fully realize NASA's vision for the future?

credit: NASA

Astronaut Peggy Whitson, shown here working on the Zeolite Crystal Growth experiment during Expedition 5 on the ISS, was chosen by NASA Administrator Sean O'Keefe to be the first ISS science officer. O'Keefe created this position in response to a recommendation by the Research Maximization and Prioritization (ReMAP) task force to demonstrate the station's strong focus on scientific research.

That was the big question that NASA's Office of Biological and Physical Research (OBPR) addressed as it built its 10-year research plan. The OBPR Research Plan, an outgrowth of the analysis and prioritization of OBPR research by the Research Maximization and Prioritization (ReMAP) task force (see ReMAP sidebar), is based in part on five organizing questions. These questions will guide the direction of OBPR scientific investigations and steer the solicitation, selection, and development of its experiments for the next 10 years.

Reaching Between Disciplines

Using questions instead of individual scientific disciplines to determine what research to solicit and support during the next 10 years provides an extra degree of flexibility. OBPR hopes the new organizing questions will encourage an interdisciplinary approach to research, generating new ideas and outcomes. This approach also avoids the potential for overlooking fruitful projects because they don't easily fit into one of OBPR's four research divisions. Using one set of questions as a guide for all research in OBPR also unifies the enterprise. These questions clearly serve NASA's goals, which, in turn, serve the overarching missions of the agency, as documented in the NASA 2003 Strategic Plan.

In late 2002, OBPR's Acting Deputy Associate Administrator for Science Howard Ross took on the task of formulating the organizing questions. His efforts resulted in five questions that OBPR research must answer to bring NASA closer to realizing its vision, which is "to improve life here, extend life to there, and to find life beyond." The questions are now the core of the new OBPR Research Plan, steering the solicitation, selection, and development of experiments to be conducted on the ground and in flight for the next 10 years. The new plan also serves as a foundation for the next step in exploration: sending humans beyond low Earth orbit.

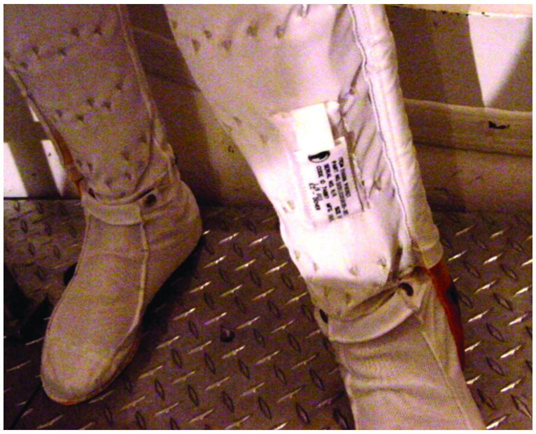
Below are the five organizing questions, followed by synopses of the kinds of research each question will involve and how the answers will contribute to the realization of NASA's vision.

The Five Organizing Questions

Question #1: *How can we assure survival of humans traveling far from Earth?*

The space environment is a challenging one, as living organisms undergo changes in microgravity and experience environmental effects such as radiation. Evidence has shown conclusively that many of these effects increase in severity when space travel is extended from short term to long term. Research is necessary both to identify detrimental effects and to devise countermeasures or methods to mitigate them.

One example of these effects is the increased rate of bone loss during spaceflight. OBPR has been studying this phenomenon and has determined that some bone mass may not return to preflight density levels for two or more years after flight. To understand and quantify the rate and distribution of loss in bone mass during spaceflight, as well as its recovery back on Earth, Principal Investigator (PI) Thomas Lang of the University of California, San Francisco, has been examining astronauts preflight, immediately postflight, and one year after flight. Through his research, Lang has found that bone loss and recovery occur differently in the two basic types of bone: cortical (found in long bones) and trabecular (found in places of stress, such as near joints of long bones and in vertebral bones). Previous research showed that while cortical bone loss is restored after spaceflight, trabecular bone loss might be to some degree permanent.



As part of OBPR's efforts to "assure survival of humans traveling far from Earth," researchers use Extravehicular Activity Radiation Monitoring experiment badges, such as the one tucked into the left boot here, to measure levels of radiation at various parts of the body. This information will help in the development of better protective measures.

Since trabecular bone mass is lost where bone is most vulnerable to stress, any degree of loss is potentially dangerous for astronauts, especially on long-term missions.

Flight research is planned or already under way to test several countermeasures, both mechanical and pharmaceutical, that have shown promise in reducing bone loss. One countermeasure is a vibrating platform developed by PI Clinton Rubin at the State University of New York, Stony Brook. Bone mass is lost in space largely because the body is not subjected to the normal stresses caused by maintaining an upright posture under gravity. Without gravitational stress, the human body realizes it no longer needs such strong bones, and bone mass is lost. The vibrating platform uses low-magnitude, high-frequency signals to reintroduce this stress by tricking the body into thinking it is in something akin to normal gravity. This countermeasure potentially could also encourage bone growth in patients on Earth, such as elderly women and the bedridden, who suffer from accelerated rates of bone loss from osteoporosis or general inactivity.

Increased exposure to cosmic radiation is another significant risk of spaceflight. The ISS is in low Earth orbit, outside the atmosphere that protects Earth from much of the radiation bombarding everything in interplanetary space. Although the ISS is shielded, astronauts are still exposed to more radiation than on Earth. They are especially vulnerable during spacewalks, when they work outside the ISS. PI Ian Thomson of Thomson Nielsen Electronics Ltd. in Ontario, Canada, recently conducted experiments on the ISS to measure radiation doses to skin, eyes, and blood-forming organs to determine where the body receives the highest levels of radiation. These data will help researchers develop more effective monitoring and shielding for the astronauts during spacewalks.

The ReMAP Task Force

To evaluate current and future plans for research aboard the International Space Station (ISS) and other facilities, NASA Administrator Sean O'Keefe in March 2002 selected members for the ReMAP task force of the NASA Advisory Council. Members of ReMAP included recognized scientists and technologists in the physical and biological sciences from academia, government, and industry.

Chaired by Rae Silver, professor of biomedical sciences at Columbia University, New York City, the ReMAP task force had two official objectives, as stated in its final report: "to assess research priorities and productivity for the entire scientific, technological, and commercial portfolio of OBPR and to provide recommendations on how to achieve the greatest progress in high-priority research." ReMAP members were made aware of some of the financial and resource limitations facing NASA but were instructed not to consider them or the platform (ISS, space shuttle, etc.) when assigning research priorities. ReMAP reviewed research in all four of OBPR's research divisions — Bioastronautics Research, Fundamental Space Biology, Physical Sciences Research, and Space Product Development. A previous task force for the International Space Station Management and Cost Evaluation had reviewed the financial aspects of the ISS program.

To David Shirley, ReMAP's vice chair and director emeritus of the Lawrence Berkeley National Laboratory at the University of California at Berkeley, the reasoning behind ReMAP's mission was sound. "During that first phase [of building a research facility] you have designers, engineers, and constructors at the helm," says Shirley. "After that, in the later stages of building and after it is finished, scientists have to take over. There is always a transition period that can be difficult. The role of ReMAP was to help move the space station through that transition by addressing scientific priorities regardless of logistics and budget."

Priorities Across Disciplines

ReMAP presented its report to the NASA Advisory Council in August 2002. The report evaluated the priority of all the research thrusts within OBPR (see OBPR Research Priorities sidebar, p. 9). Research that was given highest priority fell into two main categories: (1) research that enables human exploration of space and (2) research that has intrinsic scientific importance or impact. As those two categories match the strategic and fundamental research themes already established for OBPR, they affirmed the direction OBPR research has been taking.

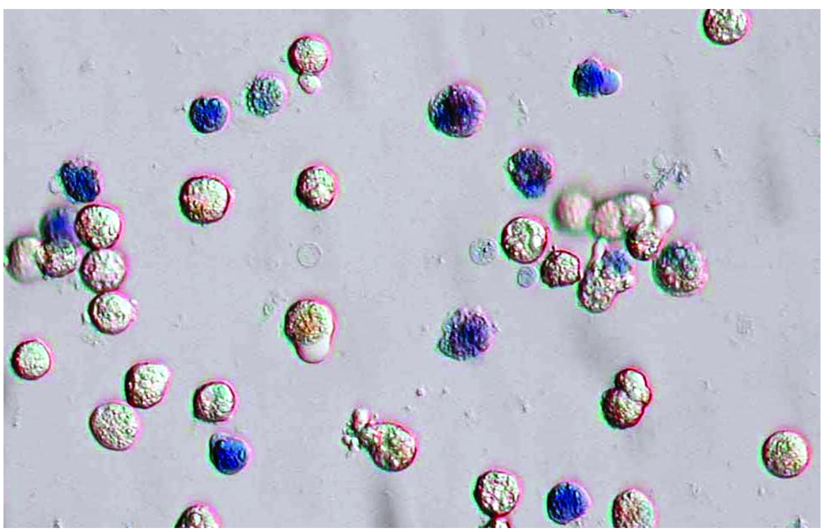
The task force made several recommendations: that OBPR's research be organized around important research questions; that the ISS be enhanced beyond U.S. Core Complete (a smaller configuration of the ISS that does not include a habitation module or crew return vehicle) before it can be characterized as a "science-driven program"; that the Centrifuge Accommodation Module from the National Space Agency of Japan be delivered to the ISS earlier than scheduled; and that one crewmember per ISS expedition (the time that a given crew is aboard the ISS) be designated as a science officer (see p. 5 for information on the Expedition 6 science officer).

credit: Joseph Tash

The purple sea urchin, a widely used model for studying the biology of fertilization, may provide insights into how reproduction is affected by gravity — essential information if humans are one day to colonize space. In experiments aboard the ISS and on the ground, investigators found that sea urchins' sperm become mobile more quickly and slow down more slowly in microgravity than they do in gravity equal to or higher than that on Earth.

In addition to the environment's effect on the body, there is the ever-present risk of injury or illness — of particular concern for longer space journeys, during which astronauts will not have access to more than rudimentary medical treatment. OBPR is developing microscopic in-vitro health monitoring and diagnostic devices to detect health changes much earlier than conventional tools. Such early-detection devices could also provide new diagnostics on Earth, especially for diseases such as cancer.

Research into clinical and operational medicine, radiation health, physiology, behavior and performance, environmental health, and biology is necessary to solve these and other potential health problems before longer-term human space travel can be attempted safely. To optimize health-risk–reduction research, OBPR has created a Critical Path Roadmap to guide researchers and medical personnel in their search for better understanding of the medical effects of space travel and the development of countermeasures. (For more information, go to *http://criticalpath.jsc.nasa.gov/*.)



credit: StelSys LLC

Microgravity is valuable for peeling away the interfering effects of gravity and laying bare functions of an organism that might not be apparent on Earth. These human liver cells were flown on the ISS and are shown after 24 hours in culture on the ground. Scientists studying how space changes life forms hope that a comparison between cells grown in microgravity and those grown on Earth will provide insight into the effects of microgravity on liver cell functions and result in a better understanding of liver functions both in space and on Earth.

Question #2: ***What must we know about how space changes life forms, so that humankind will flourish?***

Scientists are just beginning to understand the effects of gravity on the life processes of organisms at the molecular, cellular, and organismal levels. Although such understanding is valuable for predicting how organisms might react to microgravity and the low-gravity environments of other planets, the resulting knowledge addresses much deeper issues. To understand how an organism reacts to microgravity, scientists must first understand many of the fundamental biological laws and processes that govern it.

Several experiments are studying how internal organs are affected by spaceflight. One is an investigation of the effects of microgravity on liver cells. The liver has many functions, including breaking down toxins or drugs into less harmful solutions. In a joint study with OBPR, PI Albert Li of StelSys Inc. in Baltimore, Maryland, analyzed the effects of microgravity on this function of liver cells. Live liver cells were transported to the ISS, grown in microgravity, frozen, and then returned to Earth for study. The liver cells' reaction to microgravity provides researchers with valuable information about microgravity's effect on the body and may provide insights into how the liver functions in general. Results may advance the development of drugs and medical treatment for patients on Earth who are suffering from liver diseases.

Another example of research into the effects of microgravity on organisms is the recent study of the reproduction of sea urchins, led by PI Joseph Tash of the University of Kansas Medical Center, Kansas City. In experiments both ground-based and on space shuttle missions STS-81 and STS-84, Tash compared the motility (and thus functionality) of sea urchin sperm. He found that sperm become mobile more quickly and slow down more slowly in microgravity than they do in gravity equal to or higher than that on Earth. His results suggest that further study is needed to determine how microgravity could affect reproduction in space — especially important when long-term exploration and colonization become a reality. A greater understanding of reproduction may also benefit many people on Earth who suffer from reproduction disorders.

It is believed that microgravity research into cell and molecular biology (combined with molecular structures and interactions, and cell science and tissue engineering), organismal and comparative biology,

text continued on page 10

OBPR Research Priorities

OBPR Divisions	Research Themes	Research Thrusts (Prioritized by ReMAP)	ReMAP Priorities (1—4)	Organizing Questions
Bioastronautics Research	Biomedical Research & Countermeasures	Radiation Health	Priority 1	No. 1
		Integrated Physiology	Priority 1	No. 1
		Organ System Physiology	Priority 1	No. 1
		Clinical/Operational Medicine	Priority 1	No. 1
		Behavior & Performance	Priority 1	No. 1
		Environmental Health	Priority 4	No. 4
	Advanced Human Support Technology	Advanced Environmental Monitoring & Control	Priority 1	No. 4
		Space Human Factors Engineering	Priority 2	No. 3, No. 4
		Advanced Life Support	Priority 1	No. 4
		Advanced Extravehicular Activity	Priority 4	No. 4
Fundamental Space Biology	Fundamental Space Biology	Cell & Molecular Biology (See Note 1)	Priority 1	No. 1, No. 2
		Organismal & Comparative Biology	Priority 1	No. 1, No. 2
		Developmental Biology	Priority 2	No. 2
		Evolutionary Biology	Priority 4	No. 2
		Gravitational Ecology	See Note 2	No. 4
		Molecular Structures & Interactions (See Note 2)	Priority 1	No. 1, No. 2
Physical Sciences Research	Fundamental Microgravity Research	Phase Transformation	See Note 3	No. 3, No. 4
		Condensed Matter	See Note 3	No. 3
		Fundamental Laws	See Note 3	No. 3
		Kinetics, Structure, & Transport	See Note 3	No. 3
		Fluid Stability, Dynamics	See Note 3	No. 3, No. 4
		Thermophysical, Physicochemical, & Biophysical Properties	Priority 3	No. 3
	Biotechnology & Applications	Cell Science & Tissue Engineering (see Note 1)	Priority 1	No. 1, No. 2
		Structural Biology	Priority 3	No. 3
		Energy Conversion	See Note 4	No. 3
		Materials Synthesis & Processing	Priority 4	No. 3
		Bio-inspired/Microfluidics Technology	Recommends Termination	No. 4
	Engineering Research Enabling Exploration	Fire Safety & Fluid Systems Engineering	Priority 2	No. 4
		Propulsion & Power	Priority 1	No. 4
		Biomolecular Technology & Sensors	Priority 4	No. 4
		Radiation Protection	Priority 3	No. 4
		Mission Resource Production & Robotic Exploration	Priority 4	No. 4
Space Product Development	Commercial Applied Sciences	Biotechnology	Priority 3	No. 3
		Agribusiness	Priority 4	No. 3
		Advanced Materials	Priority 4	No. 3
	Commercial Engineering Research & Technical Development	Remote Sensing & Autonomous Systems	Priority 2	No. 4
		Telecommunications	Priority 2	No. 4
		Thermal Control	Priority 2	No. 4
		Power Generation, Storage, & Distribution	Priority 2	No. 4
		Robotics & Structure	Priority 2	No. 4
		Propulsion	Priority 2	No. 4

Organizing Questions

1. How can we assure survival of humans traveling far from Earth?

2. What must we know about how space changes life forms, so that humankind will flourish?

3. What new opportunities can our research bring to expand our understanding of the laws of nature and enrich lives on Earth?

4. What technology must we create to enable the next explorers to go beyond where we have been?

5. How can we educate and inspire the next generations to take the journey? (As this question relates to the Education and Outreach efforts of all divisions and not directly to the research thrusts, it is not included in this sidebar. Please see p. 11 for more information.)

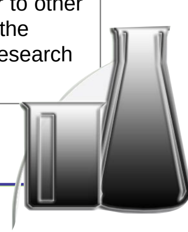
Notes

Note 1: Cell & Molecular Biology combined with elements of Molecular Structures & Interactions and Cell Science & Tissue Engineering (Physical Sciences Research). ReMAP recommended combining Cell Science & Tissue Engineering research with Cell & Molecular Biology research.

Note 2: Gravitational Ecology was not ranked because it was already represented in the Environmental Health and Advanced Life Support research areas.

Note 3: ReMAP qualified this Priority 1* ranking. Some of the projects within this area are Priority 1 because of scientific merit alone but not all are directly related to human space exploration.

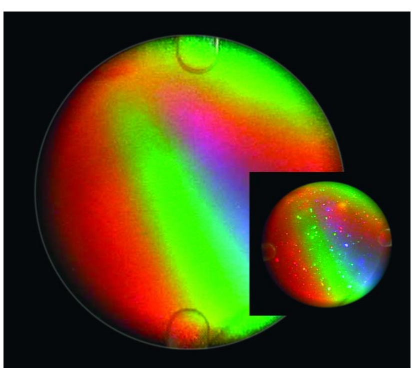
Note 4: ReMAP recommended that Energy Conversion research be integrated with other basic microgravity research as it is fundamentally similar to other investigations within the Physical Sciences Research Division.



Implementing ReMAP's Recommendations for the ISS

Lisa Guerra, special assistant to the OBPR associate administrator, says that OBPR has taken ReMAP's guidelines and created more specific versions of them to determine how to place research on the ISS manifest, according to two criteria. "One is what research can *only* be done on space station," Guerra says. "By that, we mean what research requires crew intervention or crew participation (as occurs commonly in biomedical research) and what research needs long duration in a microgravity environment. Another criterion is what research lends itself to NASA's strategic future," in other words, explorations beyond low Earth orbit.

Guerra says there is a third criterion, not considered by ReMAP during its determination of research priorities: "What research is done most *effectively* in terms of cost and timeliness on the station?" If the principal investigators for a specific project "have already invested their time and developed their experiments for the space station, it may just be too costly to change to a different platform," she explains.



credit: NASA

The Physics of Colloids in Space experiment, an ongoing investigation of the properties of colloidal systems (fine particles suspended in a fluid), is helping OBPR scientists "understand the laws of nature and enrich lives on Earth." Crystals grown in Earth's gravity (inset) are heterogeneous in size and join together to form relatively large and poorly formed poly-crystals. Crystals grown in microgravity (main image) are homogeneous, high-quality aggregates because of a lack of sedimentation.

developmental biology, and evolutionary biology will reveal answers to mysteries and take researchers that much closer to understanding life and its origins.

Question #3: ***What new opportunities can our research bring to expand our understanding of the laws of nature and enrich lives on Earth?***

One of NASA's purposes is to enhance human life on Earth. Research in microgravity can reveal phenomena that occur in everyday processes here on the ground but are masked by the effects of gravity. Investigations of energy conversion; fundamental laws; condensed matter; kinetics, structure, and transport; fluid stability and dynamics; phase transformation; human factors engineering; and biotechnology increase fundamental understanding of the physical and biological world and lead to new technologies and products.

One project that examines a basic phenomenon and also has significant applications on Earth is the Physics of Colloids in Space (PCS) experiment. PCS flew on the ISS in 2001–2002 and is scheduled to fly again in 2004 as PCS-3.

Colloids are systems of fine particles suspended in a fluid. PCS PIs David Weitz of Harvard University, Cambridge, Massachusetts, and Peter Pusey of the University of Edinburgh, Scotland, believe that their studies of colloids in microgravity have revealed valuable fundamental information about colloidal properties, particularly yielding insight into the mechanisms of aggregation, that is, the formation of gels and crystals within colloid solutions. These findings can help advance the field of photonics and the properties of products such as paints, ceramics, foods, and pharmaceuticals. PCS-3 adds two more PIs to the project: Eric Weeks of Emory University, Atlanta, Georgia, and Michael Solomon of the University of Michigan, Ann Arbor.

Another investigation of colloids, headed by PIs Paul Chaikin and William Russel, both of Princeton University, Princeton, New Jersey, is scheduled to fly on the station in 2003. PCS+ will study eight new samples of colloids using updated PCS hardware to increase the knowledge of colloidal solutions and will allow its PIs to take advantage of modifications that were made to the original hardware after the Physics of Hard Spheres experiment.

OBPR is committed to forming partnerships with industry, business, and academia to bring entrepreneurship in engineering research and development into space. Such partnerships benefit businesses by offering opportunities to do research not possible on Earth that enhance their development of better manufacturing practices and products. The partnerships benefit NASA by strengthening its bonds with the private sector and other government agencies and by sharing the financial burden involved in supporting space travel.

One research project that offers great partnership potential is the search for ways to microencapsulate pharmaceuticals to improve drug delivery. Its three PIs all hail from Texas: Dennis Morrison, Johnson Space Center, Houston; Ben Mosier, the Institute for Research Inc., Houston; and Allison Ficht, Texas A&M University, College Station. Their experiment, which flew in the space shuttle and on the ISS, was designed to enclose one or more drugs in a liquid-filled microballoon. Such enclosures have been shown to improve drug delivery and have produced very encouraging results in treatments of cancer, especially tumors. Flown on STS-95 and during ISS Expedition 5, this project has already garnered several patents; the investigators are now seeking commercial partners to further the microencapsulation technology.

Question #4: ***What technology must we create to enable the next explorers to go beyond where we have been?***

Although plans for further travel beyond low Earth orbit are still in computers and imaginations, OBPR is using the ISS to look for solutions to problems that might be encountered on longer spaceflights. For example, one challenge to all spacecraft is protection from onboard fires. In a confined craft, any form of combustion is extremely dangerous — smoldering especially so because it can invisibly release toxic by-products or suddenly burst into flames. The physics of combustion itself is different in microgravity than on Earth and thus a fire requires different responses.

PI A. Carlos Fernandez-Pello of the University of California, Berkeley, is using the Microgravity Smoldering Combustion (MSC) project to test the effect of various airflow conditions on smoldering combustion in space and on Earth. MSC has flown on several space shuttle missions, testing different conditions each time.

One study of fire-fighting techniques is the Water Mist Fire-Suppression Experiment (MIST), run by PIs J. Thomas McKinnon, Angel Abbud-Madrid, and Edward Reidel, all of the Colorado School of Mines in Golden. They are studying the use of a fine mist of water droplets instead of chemicals for fire suppression. Their objective is to determine the optimal parameters (such as water droplet diameter and different ratios of fuel to oxygen concentration) for controlling the speed of a flame in a tube, in hopes of developing effective mist fire-suppression systems for use both in space and on Earth.

Additional investigations into the problems of longer space journeys and extended stays on other planets focus on aspects of fire safety as well as environmental monitoring and control, advanced life support, enabling knowledge for propulsion and power, human factors engineering, fluid stability and dynamics, and phase transformation.

credit: NASA

A participant in OBPR's Spaceflight and Life Sciences Training Program, which encourages minority students to consider research careers, trainee Max Salganik (right) and his mentor Carlton Hall (left) examine Salganik's research project on the effect of microgravity on the growth of wheat. The program is part of OBPR's effort to inspire the next generation.

Question # 5: ***How can we educate and inspire the next generations to take the journey?***

NASA has always sought to nurture scientific curiosity and the desire to explore. Now, more than ever, the agency is committed to inspiring current and future generations to explore, to expand their horizons, and to share what they find so that our culture and civilization will flourish and our leadership remain strong.

OBPR proactively supports science education and engages the general public in space research. The Educational Outreach Program has designed a variety of classroom activities appropriate for primary and secondary (K–12) school students and teachers. Many OBPR investigators and researchers work directly with K–12 students and with college undergraduates to give them hands-on experiences in conducting research. Some OBPR student projects have flown on the ISS or the space shuttle, contributing valuable scientific knowledge.

OBPR brings space research information to public interest events such as the Experimental Aircraft Association's Airventure show in Oshkosh, Wisconsin. The Public Outreach Program sponsors exhibits at science, technology, and education conferences and gatherings. In recent months, OBPR has participated in conferences for such professional organizations as the American Society of Clinical Oncology, the National Medical Association, and the American Public Health Association. OBPR also maintains several web sites, creates multimedia interactive exhibits for museums, and publishes the quarterly full-color newsletter *Space Research*, which is distributed to educators, researchers, and members of the public who are interested in science.

A primary outreach goal is to attract promising minority students into research. For example, since 1984, the Spaceflight and Life Sciences Training Program has encouraged minority undergraduate students to pursue careers in science, technology, and engineering. In a six-week summer program, undergraduate trainees spend 60 percent of their time conducting research under mentoring scientists and engineers. Lectures are presented by researchers from NASA, academia, and various government agencies. Trainees present their research projects during the final week. They receive six credit hours from Tuskegee University, Tuskegee, Alabama, a NASA academic partner for the program.

Another goal of OBPR outreach is to share the excitement of space experiments with students. This year, the Space Product Development (SPD) Division is developing material for the Professional Development Workshop for Educators. The project includes a classroom experiment that simulates a space research experiment conducted by SPD's research partners. The purpose is to give students and educators a better understanding of how industry uses space experiments to develop innovative products that benefit life on Earth. By involving children and adults in space research, NASA shares its discoveries; increases interest in science, math, and technology careers; and secures the continuance of the great adventure of exploring space.

Without a doubt, OBPR is committed to engaging the public in current space research missions. One

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Great Things in Small Packages: Miniaturizing Chemical Detection

The need to conserve space on board spacecraft has inspired a miniaturized mass spectrometer that will be used to protect astronauts from hazardous gases and to make chemical detectors more portable on Earth.

In the vast reaches of outer space, the conservation of the "inner space" in astronauts' living quarters has always been a challenge. Astronauts are the ultimate savvy travelers: every piece of equipment they need for extended stays must be as compact as possible. Thus, miniaturization is a continual quest for NASA scientists and engineers.

One recent engineering triumph has been to shrink a crucial piece of spacecraft safety equipment, a mass spectrometer, from a refrigerator-sized rack of electronics to the volume of a shoebox. In so doing, Principal Investigator Ara Chutjian, leader of the Atomic and Molecular Collisions Group at NASA's Jet Propulsion Laboratory (JPL, Pasadena, California), and his team have developed a high-performance quadrupole mass spectrometer that is the smallest and lightest in the world. Mass spectrometers are essential cargo on crewed space missions for closely monitoring the environment both inside and outside spacecraft for toxins and leaking fluids that could threaten the astronauts' safety.

Faster, Better, Cheaper, and *Smaller*

Chutjian's quadrupole mass spectrometer is the heart of an instrument called the Trace Gas Analyzer (TGA). The TGA measures 10 x 15 x 20 centimeters (4 x 6 x 8 inches), weighs about 2 kilograms (5 pounds), and consumes just 15 watts of power — small enough to be placed on an astronaut's chestpack during spacewalks to monitor the outside environment. Chutjian and his team are working on a version for monitoring the more complex cabin atmosphere as well.

Chutjian's miniature mass spectrometer system was inspired by his efforts to meet former NASA Administrator Dan Goldin's requirement of "faster, better, cheaper." Says Chutjian, his team "added the corollary 'smaller.'"

Their reason for smaller was twofold. "There's always a call to make flight systems [spacecraft] bigger — bigger cabins and more modules. But we argue that miniaturizing components is another way to add space without adding additional modules," he says. In addition, "on missions to Mars or the outer planets — either unmanned probes or long-duration crewed flight — mass, volume, and power are all at a premium. You can't carry too much of *anything*."

Around 1992, Chutjian's team helped put together an ad hoc panel at JPL to list instruments that might be miniaturized. "Since we were all interested in charged particle optics and mass spectrometry," Chutjian recalled, "we decided that mass spectrometers would be the best candidates."

In fact, there are three mass spectrometers on the International Space Station (ISS). "They are quite large systems, taking up several electronics racks of equipment," Chutjian noted. "We think all three could be replaced by a single miniature system that would require maybe only a third of an electronics rack."

A Powerful Detector

A mass spectrometer is a powerful tool for detecting and identifying trace amounts of chemicals. Mass spectrometers are sensitive and rugged, making them ideal for use in harsh environments.

A mass spectrometer functions by drawing in a small sample of the external atmosphere, ionizing (stripping the outer electrons from and thereby giving a charge to) the gaseous components with an electron beam, and then analyzing the mass-to-charge ratio of the ionic species by a radio frequency filtering action. In a quadrupole mass spectrometer, the sample is ionized by a voltage applied to four parallel rods, or poles. By adjusting the ratio of DC voltage to radio frequency amplitude within the instrument, ions of a specific mass-to-charge ratio can be separated from the other charged species. The resulting mass spectrum, which depicts the mass-to-charge ratio and relative abundance of all species of the ions in the sample, allows scientists to determine the identity of compounds in the sample.

> A crucial piece of spacecraft safety equipment shrank from a refrigerator-sized rack of electronics to the volume of a shoebox.

Quadrupole mass spectrometers are relatively rugged and can be used for continuous sampling. The challenge for miniaturizing the instrument was maintaining sufficient sensitivity to detect the spacecraft contaminants at their critical levels — a challenge the TGA has met.

Chutjian's TGA was developed for testing the environment outside spacecraft, where there are just a few gases. "We've calibrated [the TGA] to detect seven gases. All the astronaut has to do is read the histogram bars on the instrument display." The instrument displays a running histogram; the astronaut looks at the chart and notes when a maximum signal is recorded and the time of that spike so that the leak can be detected. The type of gas being sampled can be changed by using switches on the front panel.

NASA is specifically concerned about monitoring for ammonia and hydrazine

credit: NASA

The Trace Gas Analyzer, designed to check for ammonia leaks outside the International Space Station and for hydrazine on astronaut space suits or within station airlocks, is a marvel of miniaturization. The entire instrument is about the size of a shoebox and can fit on the astronaut's chestpack for environmental monitoring during extravehicular activities.

outside the ISS. Ammonia is used to cool the skin of the space station to maintain a constant temperature within the craft. (The station's exterior can reach temperatures as high as 121 ˚C or 250 ˚F and as low as -157 ˚C or -250 ˚F, depending on exposure to the Sun.) While the station is under construction, with additional modules being added, astronauts must re-route the ammonia lines, which are coupled to one another by quick-connect fittings. Leaks are often found at these couplings, and leaking ammonia can cause the fittings to freeze shut. Astronauts need a way to check that newly connected fittings are not leaking ammonia and thus putting the station's temperature control at risk.

Hydrazine, a component of thruster propellant that is toxic to humans, is always present outside the station. It can adsorb (adhere) to spacesuits and be carried back inside the station after a spacewalk. If the TGA alerts astronauts that it has detected hydrazine outside the ISS or within its airlock, astronauts can take steps to remove it before reentering the station.

The TGA was flown to the ISS aboard Space Shuttle *Atlantis* in February 2001 and remained aboard the station for 14 months before being returned to Earth. It will be flown to the ISS again when additional space station construction requires quick-connect fittings on ammonia lines to be opened and reconnected.

Wanted: Clean Air

Inside the space station (or any other spacecraft), the air must be continuously monitored for 45 different chemicals, including such toxic gases as carbon monoxide, benzene, and formaldehyde. For this job, Chutjian's team has developed a miniature gas chromatograph to be coupled to the TGA.

A gas chromatograph uses a gas carrier to spread out a sample along a column of special material, designed to separate the sample into various components on the basis of size and chemical reactivity. Each chemical class — such as the alcohols, aromatic compounds, or ketones — exits the column at a slightly different time and directly enters the mass spectrometer, which then identifies specific compounds. For a complex mixture such as spacecraft cabin air, the gas chromatograph's preseparation allows the mass spectrometer to work with a smaller number of molecules at any one time, simplifying the task of identifying specific chemicals.

Chutjian and his team are working to determine the limits of sensitivity of their gas chromatograph–mass spectrometer system and whether it can meet and beat the station's maximum allowable concentration limits by a factor of 10, meaning that the instrument must be able to detect contaminants at concentrations a tenth the maximum allowable in the cabin atmosphere. If the new system can do this, Chutjian believes that it will be a suitable second-generation replacement for the larger systems currently in use.

Ever Smaller

Chutjian has further plans to refine the TGA. After building the mass spectrometer from commercial off-the-shelf parts, the team discovered that the electronics package was about four times bigger than the detector system itself. Chutjian says, "Now the challenge is to move away from continued miniaturization of the mass spectrometer sensor itself, which could compromise instrument sensitivity and resolution, and instead concentrate on reducing the size of the electronics." The team's first step is to get the power supplies onto a chip. Chutjian estimates that reducing the size of the electronics, which might take two years, will cut the size of the instrument by a factor of three and power consumption by a factor of two.

In Space and On Earth

Miniaturized mass spectrometers could have many uses on Earth as well as in space. Portable instruments could be useful in such applications as environmental field analysis, geological age dating (carbon dating), power plant security (detection of explosives), antiterrorism activities (detection of nerve agents, blister agents, and weapons of mass destruction), and environmental safety (detection of polychlorinated biphenyl [PCB] and perfluorocarbon tracer compounds and, potentially, pesticides).

"At this point, we consider the mass spectrometer to be like film in a camera — to a certain extent, it's simply the detector," says Chutjian. "The important area of development now is the 'front end' — not only the gas chromatography, but also ionization schemes such as negative ionization, field ionization, nanospray, and zero-energy electron attachment." He believes that improvements in these areas could lead to factors-of-10 improvements in instrument sensitivity and efficiency.

With new front ends for miniaturized mass spectrometers, Chutjian sees additional uses in space, not only for detection of compounds in air but also in spacecraft drinking water (detecting dissolved volatile organic and inorganic compounds) and, ultimately, for detection of harmful bacteria (at the single-cell level) on surfaces as well.

Aside from human safety issues, NASA may also find uses for mass spectrometers in planetary exploration. NASA will be looking for analysis systems that are low mass, volume, and power for missions to distant planets. Chutjian and his team are hoping to apply their work for human spaceflight to the robotic program — using these miniaturized instruments on robotic probes to study Mars and Venus, as well as for a Europa flyby.

Julie K. Poudrier

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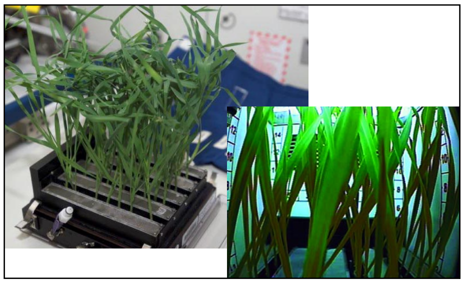
How Does Your Garden Grow?

NASA Principal Investigator Gary Stutte is conducting research to help astronauts get their greens, both nutritionally and emotionally, and ultimately to provide environmental control aboard spacecraft as well as in buildings on Earth.



credit: NASA

Dwarf wheat plants thrived in the growth chamber of the BPS. The BPS allows plants to be grown with controlled temperature, light, humidity, carbon dioxide concentration, moisture, and nutrient delivery. The growth chambers can be removed from the BPS to allow crewmembers access to the plants.

If you've ever moved from a southern sunbelt state to a northern clime, you know what it's like not to be able to get tree-ripened citrus fruit in season. Or perhaps you long for a juicy, flavorful summer tomato fresh off the vine when you're faced with its pale hothouse cousin in winter. But imagine having difficulty getting *any* kind of fresh fruit or vegetable for months at a stretch. Astronauts living aboard the International Space Station (ISS) can look out and see Earth far away, but they can only yearn for its Sun-ripened produce. And astronauts who eventually travel on long-duration missions will not have even a distant view of Earth to connect them with the gardens back home. Fresh fruits and vegetables are the mainstay of a healthful diet and a delicious connection to Earth, but providing them to astronauts is no easy task.

credit: NASA

Expedition 4 Flight Engineer Daniel Bursch, hovering in microgravity in front of the control panel for the Biomass Production System (BPS), was instrumental in the successful completion of Principal Investigator (PI) Gary Stutte's Photosynthesis Experiment Systems Testing and Operations (PESTO) experiment aboard the ISS. Bursch was responsible for collecting samples, pollinating the dwarf wheat plants, taking photographs of their growth, and performing routine care and maintenance of both plants and hardware.

Enter NASA Principal Investigator (PI) Gary Stutte. Stutte, supervisor for the plant research group of Dynamac Corporation, a life sciences contractor at Kennedy Space Center in Cape Canaveral, Florida, is researching plant growth in microgravity. He uses a plant growth facility known as the Biomass Production System (BPS), which allows plants to be grown with controlled temperature, light, humidity, carbon dioxide concentration, moisture, and nutrient delivery. The modular design of the BPS offers easy access to the growing plants for accurate assessment of their growth and functions, data and video acquisition, and a control system for integrating all diagnostics. Ultimately the BPS will lead to a larger facility for studying plant growth in space, aiding critical life support systems and allowing astronauts to enjoy some greenery in orbit or beyond.

From PASTA to PESTO

Clean air (especially fresh oxygen), pure water, and fresh food are critical for human life, and plants produce all three through their normal functions. Stutte's plant growth experiment — Photosynthesis and Assimilation System Testing and Analysis (PASTA) — was originally planned for the space shuttle but was redesigned for the ISS. "The PASTA experiment was designed to look at the effects of microgravity on the growth, photosynthesis, and reproduction of wheat," Stutte explains. "We wanted to see if we could use plants as part of a bioregenerative life support system." In other words, Stutte wanted to see if the photosynthesis could take the carbon dioxide exhaled by humans and produce oxygen. He also wanted to study the efficacy of using plant transpiration (the process of taking water in through the roots and releasing it to the atmosphere from the leaves) to purify water. Finally, he wanted to correlate the yield of the wheat plants (the amount of grain they produced) with the conditions under which they were grown.

In particular, Stutte wanted to test how microgravity affected all three plant processes. If microgravity were shown to have a negative effect on photosynthesis, transpiration, and yield, NASA would have to rethink the scale and design of advanced life support systems for long-duration spaceflight or space settlements.

"As the space station began to develop," says Stutte, "I was asked if I could adapt the PASTA experiment to a long-duration mission. Thus, the PESTO experiment was born — Photosynthesis Experiment Systems Testing and Operations." Despite the change in name and venue, the experiment's goals remained the same: measuring the effects of microgravity on fundamental life support processes at both the whole-canopy level (the green parts of the plant) and the cellular and genetic levels. PESTO was flown to the ISS in April 2002 and returned to Earth in June 2002.


credit:: Gary Stutte

NASA PI Gary Stutte (left) and Bill McLamb monitor the PESTO experiment during its 73-day mission aboard the ISS.

Going With the Grain

The first plant Stutte selected to be grown in the BPS was dwarf wheat. Stutte chose wheat for several reasons. Dwarf varieties of the same type as those grown on the space shuttle and on the Russian space station, *Mir*, were readily available. Wheat germinates quickly, grows fast, and has large leaves, which gave the researchers enough leaf area in a short time to measure photosynthesis and transpiration. Also, a significant body of literature exists on ground-based advanced life support systems with wheat, so the research team could compare its spaceflight and ground control data with existing large-scale research data. Additionally, wheat is a staple crop. It is versatile and easily incorporated into a diet in products such as pasta or bread, uses that will become more important as astronauts venture beyond low Earth orbit.

PESTO's primary objective was to see how well wheat grew under a range of environmental conditions. Inside the BPS, researchers changed carbon dioxide levels, humidity, temperature, light intensities, and other environmental variables to explore optimal ranges and to see how plant growth parameters were affected by exposure to suboptimal conditions. For example, by sharply increasing the concentration of carbon dioxide, they could simulate the presence of additional people aboard a craft and could measure its effect on the wheat's oxygen production.

Growth and Validation

The wheat research isn't solely about plant growth; it is also about validating the prototype BPS hardware, according to Orlando Santos, scientific research coordinator for the Fundamental Space Biology Office at Ames Research Center, Moffett Field, California.

"Designing this kind of hardware takes a multistage approach," says Santos. "We learn from what's been done in the past." He says, "The BPS incorporated a lot of new ideas" from previous ground-based and flight research. For example, the BPS includes an ethylene scrubber, a chemical means of removing ethylene (a volatile plant hormone) from the atmosphere. Although plants naturally produce ethylene as a by-product of growth, it is toxic to them in high concentrations. The decision to add the scrubber to the BPS was based on experimental results from growth chambers without a means for purifying the atmosphere.

According to Santos, the BPS is designed to enable plants to produce seeds. Thus, the growth chambers are tall enough to accommodate adult plants so multigenerational growth can be observed. Crewmembers, however, are responsible for pollinating the plants, a function normally performed by insects on Earth. "The next unit we're building, which is in the design phase and is tentatively called the Plant Research Unit, will build on [what we learn from] the BPS unit," Santos says.

A Good Harvest

Stutte and Santos report that the BPS performed up to all expectations. The plants grown aboard the ISS last year have returned to Earth, and results so far look promising — precisely because they vary so little from the ground-based controls. The dwarf wheat plants grown on the ISS had the same photosynthesis rates as those grown on Earth. The plants also responded the same as Earth-grown plants to variations in ambient carbon dioxide levels, light intensity, and amount of water — very good news for any plans to use green plants as part of an environmental control system on spacecraft.

But not everything was identical; subtle differences were observed. For example, plants grown in orbit were taller than their Earth counterparts. Stutte also noted changes in the efficiency of the plants' chloroplasts (chlorophyll-containing cells) — meaning that microgravity had perceptible effects at the cellular level. Now Stutte is examining genetic data to see if corresponding changes can be identified at the genetic level.

Given the results he's obtained so far, Stutte is optimistic about the prospects for plants in space. His BPS research, combined with others' research on the dwarfing of salad crops, could lead to a space version of a fresh salad bar — with the same salad plants performing extra duty as air cleaners and water purifiers.

An unanticipated but perhaps not surprising extra result was the effect of the dwarf wheat experiment on the astronauts' psychological well-being. "It's amazing how much the astronauts enjoyed working with the BPS," Santos observes. "They used it many hours above the scheduled crew time because they simply enjoyed looking at the plants." The green growing shoots provided a little piece of home in an otherwise somewhat sterile environment.

Knowledge of plant growth and photosynthesis requirements gained in space is also relevant to controlled-environment agriculture on Earth, such as that in greenhouses, the cut-flower industry, and hydroponics (growing plants in a soil-free environment using a nutrient solution and an inert medium for plant support). Moreover, the research is highly interesting for researchers studying the use of plants to control the environment in office buildings. " [Using plants] becomes a piece of a larger effort of understanding the ecosystem a little better," says Stutte. "We have collaborated with the Canadian Space Agency and the University of Guelph in Ontario, Canada, which together have a very active biological atmospheric regeneration program. They're moving into various office buildings throughout Canada and then into the United States."

Knowledge gained from the development of growth media and water delivery systems for plants in space might even be useful in further development of subirrigation systems, water-conservation techniques for arid and semi-arid agriculture conditions that direct moisture underground where roots need it rather than spraying it on top of the ground where much evaporates before crops can use it.

"In the BPS, we optimized the conditions to maximize productivity while

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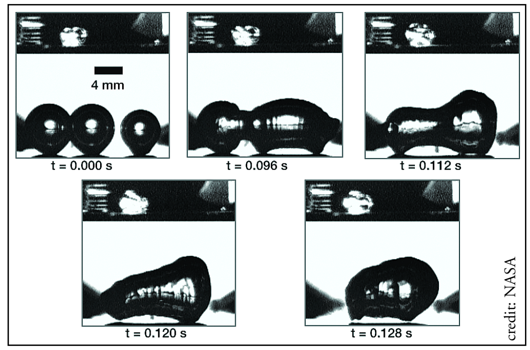
Tiny Bubbles Create Better Cooling

Vijay Dhir is looking for a safe way to build up a head of steam — and let it off — for explorers heading for the planets.

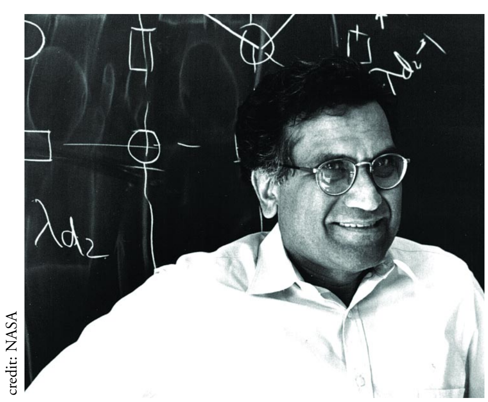


Looking like a science fiction creature, a large bubble grows as smaller ones come in contact and surface tension breaks to let the gas pockets join. The entire sequence took about 1/8th of a second.

Put a clear glass pot of water on the stove and turn the burner to high. Soon the heat turns liquid water at the bottom of the pot into bubbles of steam that almost instantly detach and zip to the surface. Cooler water flowing in behind in turn is heated to become more steam, and the entire pot boils as the transition of liquid to gas carries heat away from the stove.

Now imagine that gravity's effects are turned off. Without buoyancy to make lighter materials float to the top, the bubbles don't detach but stay in place and grow. "A single bubble could grow to about 75 cm [almost 30 inches] in diameter — darned big — in about 25 minutes," says Vijay Dhir of the University of California at Los Angeles. Dhir is principal investigator for the Investigations Associated with Nucleate Boiling Under Microgravity Conditions. His research is managed through Glenn Research Center (Cleveland, Ohio) as part of NASA's fluid physics program in the Physical Sciences Research Division.

A central concern of Dhir's program has been to understand boiling — one of the most efficient means of cooling — so it can be used safely in the microgravity of space. That includes keeping the dry heating element in this thought experiment from melting and failing altogether. Another scenario involves water flowing through a cooling tube. In that case, if a growing bubble of steam were to slide along the surface of a heating element and enter an inlet for a cooling system, it could block further flow — classic "vapor lock" that often caused older cars to overheat. Either way, trouble could be brewing. A stove, a power plant, a computer, or any other active system — including a spacesuited human — must shed heat or break down.



Vijay Dhir of UCLA.

Dhir hopes that his research will show how to design cooling systems for spacecraft — and even for terrestrial systems — to avoid such dangers in weightlessness. His pilot experiments, conducted aboard NASA's KC-135 parabolic aircraft, have uncovered a new aspect of the physics of boiling that he hopes to explore in detail with extended-duration experiments aboard the International Space Station (ISS).

Boiling Questions

The energy required to vaporize any liquid is significant, and thus energy moves from one location to another. When enough heat leaves for the gas to condense back into a liquid, the cycle is complete. Boiling has been fundamental to modern industry since the dawn of the Steam Age in the late 18th century, yet it is still poorly understood in many respects, especially where gravitational effects are involved. "No one has really addressed how boiling scales with gravity," Dhir says, referring to how the physics of boiling changes as gravitational fields decline from 1 *g* on Earth to the microgravity of orbit. "What are the key physical variables that are important?" On Earth, physicists simply have not had a need to describe all the physical aspects of what happens as a liquid bubbles and carries heat away.

In space, however, the removal of gravity's effects from boiling allows other forces to dominate and be observed, just as it has with many other physical phenomena. In microgravity, the roles of the liquid's viscosity, the recoil of vapor bubbles (controlled by the surface tension of the bubble), the interaction of bubbles with one another, the resulting departure force, and other effects must be understood better if boiling systems are even to work, much less be optimized.

Low-*g* boiling experiments have a long history, starting with drop-tower tests at Glenn in 1964 and continuing through space shuttle experiments in the 1980s and 1990s. While those studies produced valuable insights into the boiling phenomenon, Dhir maintains that the findings were inconclusive and sometimes contradictory, pointing to different mechanisms.

To resolve some of the inconsistencies, Dhir has designed an experiment that allows precise control of the locations where bubbles form and the timing of their release (see Boiling Chips sidebar) — something that the design of earlier microgravity experiments did not permit. For example, patterned surfaces will allow Dhir and his colleagues to study boiling across a range of controlled variations, to quantify how heat moves from a solid surface into liquid and then to vapor and how heat transfer in one tiny area can affect transfer in another.

With tantalizingly short experiments aboard the KC-135 in 2000, Dhir has already uncovered some surprises about how fluids boil in microgravity. During some 60 parabolas (adding up to 20 minutes of low-*g* time), he found that while a single bubble can grow to dangerously large sizes in low *g*, the release of even a few small bubbles can create radically different flow patterns that induce additional bubbles to depart. “Multiple interacting bubbles create their own lift force,” Dhir says. “This is a new thing we discovered that nobody else has studied.”

Nonetheless, in the KC-135 microgravity experiments, the average bubbles grew to 20 mm (more than 3/4 inch) in diameter when water was boiled and to almost 6 mm (1/4 inch) in PF-5060, a synthetic fluid — some seven times the size of bubbles produced when the same apparatus was operated in 1 *g*.

Dhir’s team is looking at more than just the sizes and rates of bubble formation. They are also fascinated by what happens in the vanishingly small wedge formed as the bubble’s edge curves inward to meet the solid surface of the heating element. Heat transfer in the wedge becomes more vigorous, as there is less and less liquid between the heat source and an expanding bubble. In microgravity, surface tension, wetting, and other characteristics become important to a bubble’s creation and growth.

Moreover, Dhir’s computer simulations show that if the bubbles are neatly lined up like beads on a string, they have little effect on each other. But if their positions are staggered, they merge and induce circulation and lift forces that move other bubbles away from the heating surface as well. To Dhir, this discovery suggests that patterning a surface with deliberate, microscopic variations might induce proper boiling in a low-*g* heat-transfer system.

“You could exploit it,” Dhir says, “but first we need to understand the physics.”

To Orbit, to Earth, and Beyond

Studying boiling problems has led Dhir to look skyward — and then back down again. “I’ve been studying boiling for three decades, looking at Earth-normal [1 *g*] gravity,” he says. “I want to see if we can predict boiling heat transfer rates.” Now he wonders whether what he’s discovered in microgravity might also be useful back on Earth. For example, he says, “Patterning a surface might be highly useful, especially if you were using liquid metal in, say, a sodium-cooled reactor” such as that used in nuclear submarines or some power plants in 1 *g*. “We can develop efficient boiling systems,” he says. “The question is, can I do better? If I truly understand the physics of boiling, then I can design a better surface that will perform the way I need.” For example, the fuel rods of nuclear reactors have natural cavities in their exterior surface to induce boiling. “If I can design the cladding with cavities to get twice the heat flux at a lower temperature,” Dhir says, “then it is more fuel efficient.”

In 5 to 10 years, Dhir expects that the result of a successful ISS investigation could be design codes that engineers would use to optimize surfaces in a boiling system for a range of applications, both on Earth and in space. “That is my ambition, my life’s goal,” he says. If he succeeds, he will write new chapters in the physics of boiling. Such profound understanding could help thermal engineers design space applications ranging from nuclear electric propulsion systems powering space vehicles between planets to electrical power plants and cooling systems operating efficiently in the fractional gravities on other worlds.

Dave Dooling

For additional information on Dhir’s research, visit the following Web sites: *http://microgravity.grc.nasa.gov/fcarchive/fluids/papers/Dhir/A_Mechanistic_Study.htm*, *http://ncmr04610.cwru.edu/events/fluids1998/papers/459.pdf*, and *http:// www.grc.nasa.gov/WWW/RT1999/6000/6712chao1.html*.

For information on the Boiling Heat Transfer Lab at UCLA, visit *http://boiling.seas.ucla.edu/boiling/*.

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Boiling Chips

To control boiling in his microgravity experiments, Vijay Dhir uses a sophisticated version of an old trick — small stones added to water to prevent it from superheating, a condition in which it rises above boiling while remaining liquid and can boil explosively when disturbed. In Dhir’s experiments, the “stones” are actually chips: silicon wafers 10 cm (4 inches) in diameter, similar to the backbone of electronic chips. Dhir’s silicon wafers are dimpled with tiny wells only 4, 7, or 10 microns wide and 100 microns deep, and each well is backed by a tiny heating element. The wells serve as nucleation sites where water heats to boiling and then turns to vapor. Each well or combination of wells can be heated to produce a single bubble or an array of bubbles. A bellows reduces pressure on the fluid so boiling can be induced on demand.

In Dhir’s experiment, a high-speed video camera with a macro lens provides close-up images of the bubbles as they form. A small pump can move a bubble along a surface to simulate conditions that might lead to vapor lock, a condition in which a gas bubble blocks a line that should be passing liquid.

Two liquids are used. One is water, a cooling agent used in boiling systems since Hero built the first steam engine in 200 B.C. The other fluid is PF-5060 (3M’s perfluorohexane), a fluorocarbon 1.5 times as dense as water, with a much lower surface tension. It forms smaller bubbles as it boils, making it ideal as a model for larger water volumes than Dhir could hope to assemble in a space experiment. The KC-135 experiments have used 3 liters (5.2 cups) of fluid; those on ISS will hold less, just 1.5 liters (2.6 cups), to fit into the work volume of the Microgravity Science Glovebox.

Dhir’s flight experiment passed its requirements definition review (RDR) in December 2002. That clears the way for initial design of flight hardware that would be operated by astronauts using the Microgravity Science Glovebox. If all goes well, the flight could follow in three years or so, depending on demands on ISS resources. The experiment volume inside the glovebox, while more generous than that of earlier gloveboxes on the space shuttles, will restrict Dhir to studying the formation and release of multiple small bubbles rather than the growth of a single large bubble.

Steering Satellite Technology in the Right Direction

Serving as an economical test bed for advanced satellite components, the International Space Station will soon help tomorrow's commercial spacecraft technologies meet the unique rigors of low Earth orbit.

In perhaps five years, industry will have an economical test bed for trying out advanced commercial satellite technology in low Earth orbit, thanks to the EXPRESS pallet (ExP) to be added to the International Space Station (ISS). In the past, if a company wanted to test or demonstrate new solar arrays, antennas, sensors, or other components in the environment of space, it had to arrange to build its own technology demonstration satellite — an expensive and time-consuming venture, even if shared among industrial partners — or wait for the goverment to build one. With the launch of the first ExP in 2008, however, the cost of testing satellite technology in space is expected to decrease.

The ExP is part of NASA's EXPRESS program to EXpedite the PRocessing of Experiments to the Space Station. The pallet complements the EXPRESS racks, which are five vending-machine-sized cabinets designed to transport, store, and support an assortment of experiments with power, cooling, and data capabilities. The final rack was installed in June 2002 inside Destiny, the U.S. lab module aboard the ISS. While the racks provide efficient space for pressurized payloads inside Destiny, the pallet is for nonpressurized payloads secured to the outside of the ISS in the vacuum of space. The EXPRESS pallet will piggyback on the truss or framework supporting the station's solar panels. The ExP to be launched in 2008 is the first of a total of four pallets planned for the ISS; three more are scheduled for installation later. Two of the pallets will be attached to face Earth (nadir) and two to face away from Earth (zenith).

The demands of microgravity and vacuum are considerable, but thermal cycling has a punishing impact on space equipment — especially in low Earth orbit.

With the EXPRESS pallet, the Commercial Space Center for Engineering (CSCE), headquartered at Texas A&M University in College Station, Texas, offers industry the opportunity to use the ISS as an engineering research platform. "The ISS is a unique and potentially valuable test bed for advancing spacecraft technology," says CSCE Director David Boyle. NASA's Space Product Development program sponsors the CSCE and 14 other research partnership centers to help American businesses explore the potential — and reap the rewards — of doing business in space. These research partnerships help bring the benefits of space down to Earth, where they can enrich the everyday lives of the American public.

Equipment Endurance

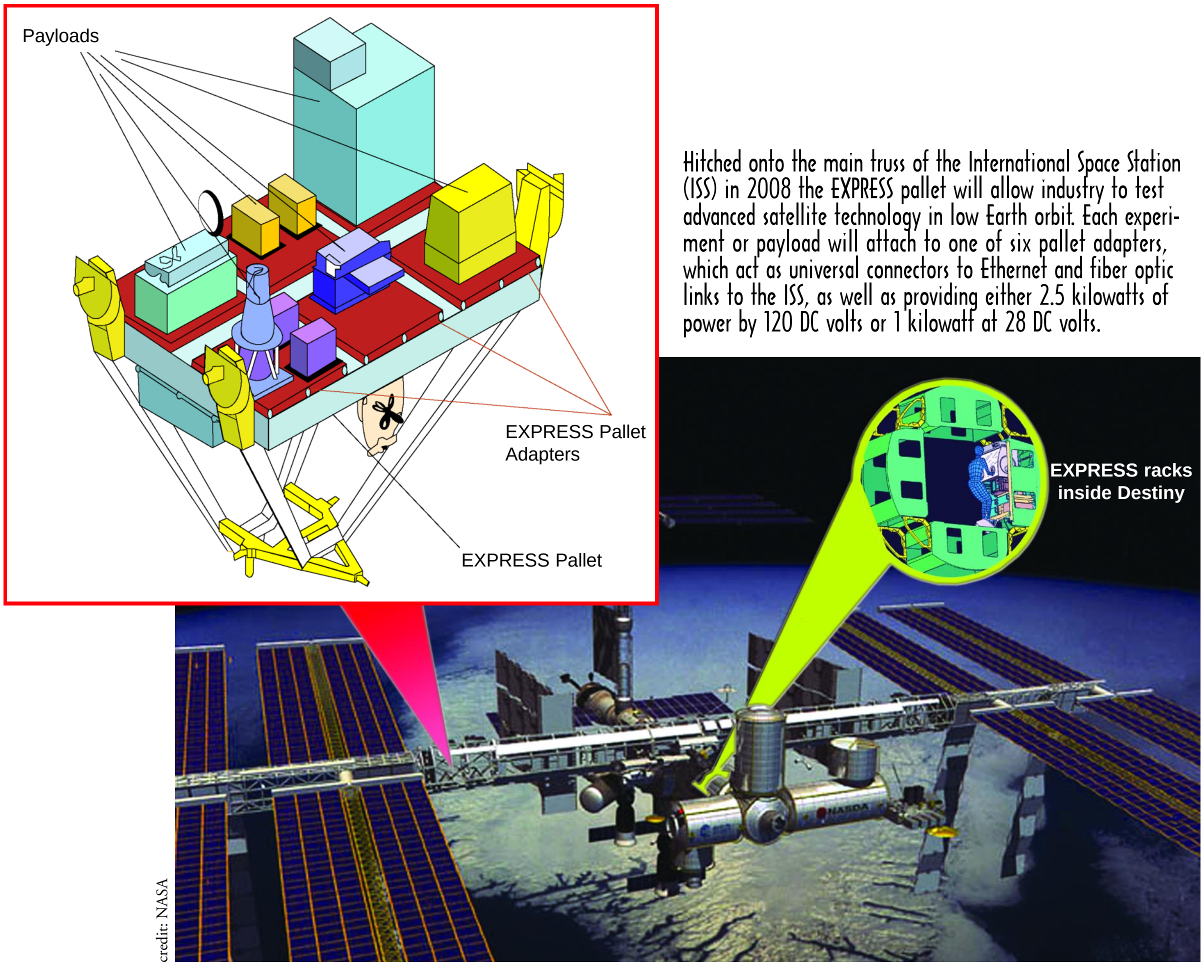
Companies want to ensure that their products will operate at peak performance in the harsh environment of space. The demands of microgravity and vacuum are considerable, but thermal cycling also is hard on space equipment.

Thermal cycling is the effect of being bathed in alternating hot and cold temperatures from different sources. In just about any Earth orbit, a spacecraft will spend part of its time in sunlight and part in Earth's shadow, with its temperature swinging hundreds of degrees. In low Earth orbit (LEO), a space vehicle with a 90-minute orbit goes from shadow into direct sunlight and back 32 times a day. But thermal cycling is especially acute in LEO at about 300 to 400 km (180–250 miles) high. In LEO, a space vehicle receives radiant thermal energy from three primary sources: solar radiation from the Sun, solar energy reflected from Earth's surface, and outgoing long-wave radiation emitted by the Earth and its atmosphere at levels that vary around the globe depending on geographical (land vs. ocean) and atmospheric (cloudy vs. clear) conditions. This variation causes a space vehicle to experience continuous change in thermal radiation as it travels across the global thermal profile.

In short, a space vehicle in LEO is erratically heated and cooled. The temperature fluctuation causes its hardware to expand and contract, deteriorating equipment and materials.

In geosynchronous Earth orbit (GEO) — about 36,000 km (22,500 miles) above Earth's equator — a satellite appears to stay over the same point on Earth at all times. This 24-hour orbit is most commonly used by communications and weather satellites, so that receiving antennas on Earth can remain aimed at the same point in the sky. In GEO, thermal cycling is less severe, as the satellite spends a good share of each year in full sunshine above or below the cone of Earth's nighttime shadow. Also, since the higher orbit is 10 times farther away from Earth than LEO, geographical or atmospheric variations in thermal energy from Earth have less influence. NASA uses geosynchronous satellites to relay communications and data among spacecraft or from spacecraft to the ground, such as from the space shuttle and the Hubble Space Telescope to control centers on Earth.

"Most companies send their communications satellites to geosynchronous orbit," says Boyle, "but some see potentially valuable applications in low Earth orbit as well. The radiation levels in LEO are different from those at GEO, but experimenters can learn much about radiation effects from the actual exposure to the LEO space environment." A test platform in LEO is exactly what the EXPRESS pallets on the ISS will offer.



Hitched onto the main truss of the International Space Station (ISS) in 2008 the EXPRESS pallet will allow industry to test advanced satellite technology in low Earth orbit. Each experiment or payload will attach to one of six pallet adapters, which act as universal connectors to Ethernet and fiber optic links to the ISS, as well as providing either 2.5 kilowatts of power by 120 DC volts or 1 kilowatt at 28 DC volts.

credit: NASA

Nuts and Bolts

Each ExP is about 2 meters wide by 3 meters long (6 by 10 feet) and has a 1.4-metric-ton (3,000-pound) total payload capacity. It will accommodate up to six experiments, each built on an individual EXPRESS pallet adapter (ExPA) — essentially a receptacle for plugging in industry-supplied experimental payloads such as prototypes of new spacecraft technology. Each ExPA provides its payload with an ISS power supply and a data transfer rate of 1 Mbps (megabits per second) through the station's communication system.

The ExPA-mounted experiment payloads will remain locked on the EXPRESS pallet for the duration of their testing periods, which could be six months to a year. When it's time to remove a payload, the space station's Special Purpose Dexterous Manipulator, or Canada Hand, will unlock its pallet adapter from the pallet and place it into a space shuttle's cargo bay for the trip home. (Originally scheduled for launch this year, the Canada Hand is the third portion of the ISS's robotic arm; it is a smaller two-armed robot capable of handling delicate assembly tasks currently performed by astronauts during spacewalks.)

First Experiments

Although the first EXPRESS pallet won't be sent to the ISS for another five years, six commercial payloads have already been proposed. Two focus on advanced systems for commercial remote sensing and communications satellites in LEO.

With the first payload, the Remote Sensing Technology Laboratory in Space experiment, companies such as TRW, Raytheon, PetroSat Inc., and Hamilton Sundstrand could test and demonstrate advanced imaging systems such as hyperspectral sensors. Hyperspectral sensors, similar in execution to an older technology called multispectral imaging, subdivide the spectrum of ultraviolet, visible, and infrared light into distinct groups and create multiple images using these groups of the electromagnetic spectrum. For example, with multispectral imaging, if the proper wavelengths are selected, the technology can be used to detect camouflage (for military purposes), thermal emissions, and hazardous wastes. By creating even more images using adjoining bands of light, hyperspectral sensors can discriminate, classify, identify, and quantify specific materials in the target area and yield a picture with finer resolution. For instance, when used from a satellite, the imaging technique can identify a tank concealed in camouflage or distinguish between an oak and a maple in a forest. The Remote Sensing Technology Laboratory in Space experiment is designed to determine the spectral sensitivity of advanced sensors that will increase the resolution of existing top-of-the-line hyperspectral sensors. Higher resolution imaging would open new markets for affordable and timely information regarding energy resources, agriculture, urban planning, and homeland defense.

The communications satellite payload experiment planned for the first EXPRESS pallet by industry partners including Harris, Raytheon, and TREX Enterprises will test the viability of phased-array antennas and laser systems for broadband communications in LEO.

Unlike conventional antennas that must be mechanically pointed to direct a signal toward a receiver, phased-array

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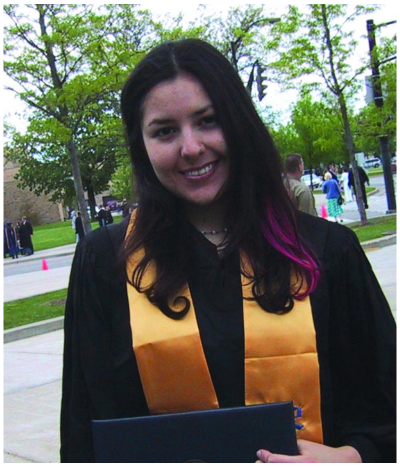
Sending Students Onward and Upward

Student participants in NASA internships gravitate toward science-based careers.



credit: NASA

Denise Fraga's experience as an intern for OBPR's Cellular Biotechnology Office at Johnson Space Center influenced her current plans for international work and medical study.

For decades, space exploration has attracted countless men and women to scientific research. The NASA adventure continues to challenge and inspire newcomers through educational opportunities that encourage undergraduates and graduate students to try out science careers. NASA's Office of Biological and Physical Research (OBPR) offers internships and student opportunities in fundamental biology, the physical sciences, bioastronautics, and research partnerships. These internships have helped students further their education while discovering potential future careers.

Reaching for the Stars

Take Jesse Leaman, who interned at Marshall Space Flight Center (MFSC) in Huntsville, Alabama, in the summer of 1998 and spotted his niche swirling in and out of our galaxy. Under the guidance of Dan Woodard, lead for NASA Physical Sciences Outreach and Education, Leaman broadened his knowledge of space research as he created educational Web pages for the microgravity division. But it was one intense week spent in Marshall's space sciences lab that introduced Leaman to his future career path. Leaman says he found out that astrophysics interested him the most. While the entire internship gave him "a good introduction into the workings of a big organization like NASA" — the way it conducted business and its strong emphasis on teamwork — Leaman knew he wanted to pursue the stars.

credit: NASA

After earning his doctorate, Jesse Leaman will continue to pursue research into extragalactic phenomena, in cooperation with NASA.

As a teen, Leaman had dreamed of becoming a marine biologist. In high school, his plan was to attend the Florida Institute of Technology and major in marine biology. Unfortunately, during his senior year, this dream ended abruptly. A tragic, unsuccessful stunt off his 15-foot high porch resulted in a broken neck and several shattered vertebrae.

Paralyzed from the shoulders down, Leaman remained strong-minded and determined. He was inspired by world-famous disabled astrophysicist Stephen Hawking to study astronomy. He enrolled in East Stroudsburg (Pennsylvania) University, conveniently located in his hometown. After three semesters, Leaman applied and was accepted as a student intern at MSFC. This was a personal challenge, Leaman says, because "the MSFC internship meant leaving the security of my home and family for the first time since my accident." However, the internship "provided a basis for many of the decisions I made afterwards in terms of feeling comfortable moving to other places with or without family support." He continued to pursue space science in the summer after his sophomore year, at NASA Goddard Space Flight Center (GSFC) in Greenbelt, Maryland. As a student intern in the Space Physics Data Facility, Leaman analyzed data from the spacecraft *Geotail*.

"Astrophysics is just fascinating to me," Leaman says, "and it's just challenging enough to keep me interested." He is interested in supermassive black holes, cosmology, dark matter, dark energy, and instrument calibration.

Today, Leaman is enrolled in a doctoral program in astrophysics at the University of California at Berkeley; he continues to co-op at GSFC during the summers.

Building a Repertoire

As a sophomore at the University of Notre Dame in South Bend, Indiana, Denise Fraga knew she wanted to find a NASA internship. With high hopes, she began e-mailing her curriculum vitae along with future goals to people listed on the NASA homepage, including Bonnie McClain, OBPR chief of educational outreach. Through correspondence with McClain, Fraga found an internship at Johnson Space Center in Houston, Texas, working with Steven Gonda in the Advanced Technology Development Laboratory in the Cellular Biotechnology Office in the summer of 2000.

In Gonda's lab, Fraga helped develop a NASA-funded flight experiment to

NASA's Office of Biological and Physical Research offers a smorgasbord of student awards, internships, and programs in fundamental biology, the physical sciences, bioastronautics, and research partnerships.

determine the effects of the space environment (such as gamma rays that penetrate spacecraft) on the human body. "Working in Dr. Gonda's lab provided me a foundation for learning new laboratory techniques and understanding how a research lab operates," Fraga recalls. "I was responsible for ordering my own supplies for my project, keeping organized notes on my experiments, doing research, and reading journals to support new experiments." That experience, along with two additional summers donning a lab coat, prepared her for future opportunities.

Meanwhile, Fraga's younger cousin developed neuroblastoma (a cancer that commonly affects children) and was referred to St. Jude Children's Research Hospital in Memphis, Tennessee. This family experience drew her interest to pediatric oncology research. "After working at NASA, I qualified for a student internship at St. Jude as part of the Pediatric Oncology Education Program," says Fraga. Not only did she qualify, she interned there for two summers, in 2000 and 2001.

In December 2002, Fraga graduated from Notre Dame with a bachelor's degree in biochemistry. She is considering an international program before applying to Stanford Medical School, in Stanford, California, to earn her doctorate. "My plans are still evolving," Fraga says, "but I know I want to learn another language and do some international work before going to medical school. I don't think we excel as human beings and members of the global community unless we challenge ourselves to do different things on different levels."

Springboarding to Opportunities

Rather like climbing a flight of stairs, Anabelle Matos progressed through several NASA internships before gaining a senior research microbiologist position with the U.S. Department of Agriculture (USDA).

Matos discovered her first NASA program by chance in 1991. Between classes at the University of Puerto Rico, she was wandering the halls of the natural sciences building when she saw a poster describing NASA's Spaceflight and Life Sciences Training Program (SLSTP). She picked up a postcard for requesting additional information and an application package. "I went back to the building the next day, and the poster was gone!" Matos recalls. "It was destiny that I was at the right place at the right time to see it."

In January 1992, Matos transferred to the University of South Florida in Tampa, and that summer she began the SLSTP internship at the Kennedy Space Center (KSC) in Cape Canaveral, Florida. SLSTP offers an intensive, six-week summer training for undergraduates interested in learning how to design experiments and conduct biological research and operations in space. During her internship, Matos examined leaching and combustion as possible ways to use recycled inedible plant biomass as a source of nutrients for plants grown hydroponically (in a soil-free environment using a nutrient solution and an inert medium) during long-term missions. "I also worked on a project that designed exercise equipment and fun aerobic games to be performed in space," she adds.

"SLSTP was a wonderful experience," Matos says. "It helped me focus and it opened a lot of doors. I met people who have played an important role in my career, many of whom are still in my life."

After her introduction to NASA, Matos returned to the University of South Florida and finished her bachelor's in interdisciplinary life sciences with a concentration in biology. After graduation, she accepted another OBPR research experience at KSC. As a planetary biology intern, she studied the structure and function of microbial communities in a closed system.

Over the next six years, Matos earned a master's in microbiology and a Ph.D. in biology from the University of South Florida. She worked as a NASA graduate research fellow with Jay L.

credit: NASA

After early dreams of becoming a pediatrician, Anabelle Matos says her first biology class in the seventh grade turned her head toward biology.

Garland, chief scientist of Space Life Sciences and Ecological Research at Kennedy and a principal investigator Matos had met through SLSTP.

In 1999, Matos became the first Hispanic woman to receive a doctorate from the University of South Florida. She is grateful for the opportunity to complete her graduate research at KSC. "KSC is a truly inspiring and magical place for me," says Matos. "It gave me the opportunity to work with great scientists who changed my life and continue to inspire me."

Today, Matos is a senior research microbiologist with the USDA Agricultural Research Service. She is also a USDA/NASA liaison, bringing the two federal agencies together by identifying areas of mutual interest. In a USDA/NASA collaboration, Matos is now researching new treatments to control the growth of harmful pathogens such as *Salmonella* on alfalfa sprouts. She also helps recruit students for USDA/NASA research opportunities and has several SLSTP students doing research in her own laboratory.

Standing for Responsibilities

Ted Bateman first experienced NASA's space research opportunities as an SLSTP intern in the summer of 1991. Ted was between his junior and senior year as a physics major at DePauw University in Greencastle, Indiana, and had learned about SLSTP through a

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What's Happening on the International Space Station?

This new department of Space Research *will describe experiments being conducted on the International Space Station.*

Although the International Space Station (ISS) is still under construction, crewmembers are making time to conduct numerous experiments for the principal investigators (PIs) of the Office of Biological and Physical Research (OBPR). Following are brief descriptions of current research aboard the ISS, starting with the arrival of the Expedition 6 crew in November 2002.

The Bioastronautics Research Division has two new experiments: "Chromosome" and "Foot." Chromosome, short for Chromosomal Aberrations in Blood Lymphocytes of Astronauts, is designed to look at the effects of exposure to space radiation on human chromosomes. On Earth, aberrations in chromosomes have been shown to increase cancer risk, so assessing the effects of radiation on human chromosomes in orbit will help NASA plan the safest possible spaceflight missions.

PI Günter Obe of the University of Essen in Germany obtained blood samples from astronauts before their flight to the ISS. He will draw additional blood samples immediately upon the astronauts' return and qualitatively compare the scores for chromosomal aberrations in both samples. This information on the chromosome-breaking effects of space radiation in blood lymphocytes will be gathered for each chromosome pair. Obe will also see how each pair participated in distributing the aberrations within itself and to neighboring chromosomes. The experiment will run from November 2002 until October 2003. Earlier versions of this experiment were run on *Mir* and *EuroMir*.

"Foot," short for Foot Reaction Forces During Spaceflight, is the experiment of PI Peter Cavanagh of Pennsylvania State University in University Park. In microgravity, stress on the bones and muscles of the legs and feet is greatly reduced compared with stress under the normal gravity of Earth. In fact, studies have shown that during spaceflight bone mineral is lost from the proximal femur (the part of the femur closest to the body) at a rate greater than 1.5 percent per month, and that knee extensor muscle strength is reduced by as much as 20 percent during 60- to 80-day flights.

Cavanagh will estimate astronauts' bone mineral density, muscle cross-sectional area, and joint torque both pre- and postflight to quantify the requirements placed on bone and muscle during typical daily activities both on Earth and on the ISS. The pre- and postflight estimates will provide data for making necessary changes in astronauts' activity profiles from Earth to orbit and will help to lay a foundation for building countermeasures for preventing bone and muscle loss while on the ISS or future long-duration space missions.

Although previous experiments have looked at bone density and muscle strength, Foot will be the first attempt to measure extremity loading in flight and to determine how such loading affects both muscle and bone. Foot will run from November 2002 until February 2004.

Other bone and muscle experiments being conducted on the ISS are Subregional Assessment of Bone Loss in the Axial Skeleton in Long-Term Space Flight (Subregional Bone); Effect of Prolonged Spaceflight on Human Skeletal Muscle (Biopsy); and Effects of Altered Gravity on Spinal Cord Excitability (H-Reflex).

For information on new and ongoing experiments on the ISS, visit *http://spaceresearch.nasa.gov/research_projects/ros/ros.html.*

credit: NASA

Expedition 6 Commander Ken Bowersox jogs on a treadmill in the Zvezda Service Module aboard the ISS. To obtain data for the Foot experiment, Bowersox is wearing the Lower Extremity Monitoring Suit, which is designed to measure stress on lower extremity bones and muscles during everyday activities.

RESEARCH OPPORTUNITIES

http://research.hq.nasa.gov/code_u/code_u.cfm

Research Opportunities in Physical Sciences

The fiscal year (FY) 2003 NASA Research Announcements (NRAs) for the five discipline sections of the Physical Sciences Research (PSR) are as follows:

- **Biotechnology:** NRA-02-OBPR-03-A opened April 30, 2003, with proposals due July 31, 2003. The NRA involves research to produce bioproducts that will enhance human health and welfare.
- **Combustion Science:** NRA-02-OBPR-03-B proposals were due March 28, 2003, with selections expected by September 2003. The NRA solicits research into fire safety, pollution reduction, and combustion-related product development.
- **Fluid Physics:** NRA-02-OBPR-03-C opens September 10, 2003, with proposals due December 10, 2003. The NRA seeks research that explores fundamental physics and the dynamics of simple and complex fluids.
- **Fundamental Physics:** NRA-02-OBPR-03-D proposals were due April 25, 2003, with selections to be made in October 2003. The NRA seeks research that investigates the basic laws that determine the properties of the physical world.
- **Materials Science:** NRA-02-OBPR-03-E opens June 30, 2003, with proposals due September 30, 2003. The NRA solicits proposals that study and develop new materials or new uses for known materials.

Further information on these announcements can be found on the World Wide Web (WWW) at *http://research.hq.nasa.gov/code_u/open.cfm*.

Selections are still being made for the PSR Division's NRA for 2002:

- **Biotechnology:** NRA-01-OBPR-08-B proposals were due September 3, 2002, and selections are expected in May 2003.
- **Fluid Physics:** NRA-01-OBPR-08-D proposals were due December 2, 2002, with selections to be made in June 2003.
- **Special Focus Theme, Materials Science for Advanced Space Propulsion:** NRA-01-OBPR-08-G proposals were due September 3, 2002. Selections were made in the spring and awards will be presented later in 2003.

For more information on these announcements, see *http://research.hq.nasa.gov/code_u/nra/current/NRA-01-OBPR-08/index.html*.

Research Selections Made for Fundamental Physics

NASA has selected 14 researchers to receive grants totaling more than $5.2 million over four years to conduct fundamental physics research on Earth and in space. Eight of the grants are for ongoing research and six represent new projects. Fifty-one proposals were received in response to research announcement NRA-01-OBPR-08-E. See *http://spaceresearch.nasa.gov/general_info/OBPR-03-046.html* for more details.

Join National Cancer Institute/NASA Solicitation

The National Cancer Institute and NASA solicited projects through a Broad Agency Agreement (N01-CO-27042-32) titled "Fundamental Technologies for the Development of Biomolecular Sensors." The deadline for applications was November 1, 2002, and awards are expected in the fall of 2003. For more information, see *http://rcb.cancer.gov/rcb-internet/appl/rfp/27042/toc.pdf.*

Research Opportunities in Bioastronautics

- The Bioastronautics Research Division solicited proposals for the ground-based study of space radiation biology and space radiation shielding materials. Responses to this announcement (NRA-02-OBPR-02) were due November 25, 2002. Selections are expected to be made in 2003. For more information, go to *http://research.hq.nasa.gov/code_u/nra/current/NRA-02-OBPR-02/index.html.*
- The Advanced Human Support Technology program in the Bioastronautics Research Division is soliciting research proposals through NRA-03-OBPR-01. Research will support advanced environmental monitoring and control, advanced life support, and space human factors engineering. Proposals are due June 13, 2003. For more information, go to *http://research.hq.nasa.gov/code_u/nra/current/NRA-03-OBPR-01/NRA-03-OBPR-01.pdf.*

Research Opportunities in Space Radiation Biology

NRA-03-OBPR-02 solicits research proposals for NASA Specialized Centers of Research in support of space radiation research in the Bioastronautics Research and Fundamental Space Biology Divisions. Selected research will be conducted using the ground-based irradiation facilities at the NASA Space Radiation Laboratory at Brookhaven National Laboratory in Upton, New York. Proposals are due June 2, 2003. For more information, go to *http://research.hq.nasa.gov/code_u/nra/current/NRA-03-OBPR-02/NRA-03-OBPR-02.pdf.*

TECHNICAL MEETINGS

Biotechnology Industry Organization 2003 Annual Convention

Washington, D.C.
June 22–25, 2003
http://www.bio.org/events/2003/

This year's Biotechnology Industry Organization (BIO) convention will bring together 20,000 leaders in biotechnology and the life sciences for BIO's 10th anniversary. Events will include a public healthfest, career fair, roundtable discussions on ethics and the Food and Drug Administration, several business forums, an exhibit hall, and plenary lectures. The National Institutes of Health director's lecture series will be presented and the BIO annual membership meeting will be held.

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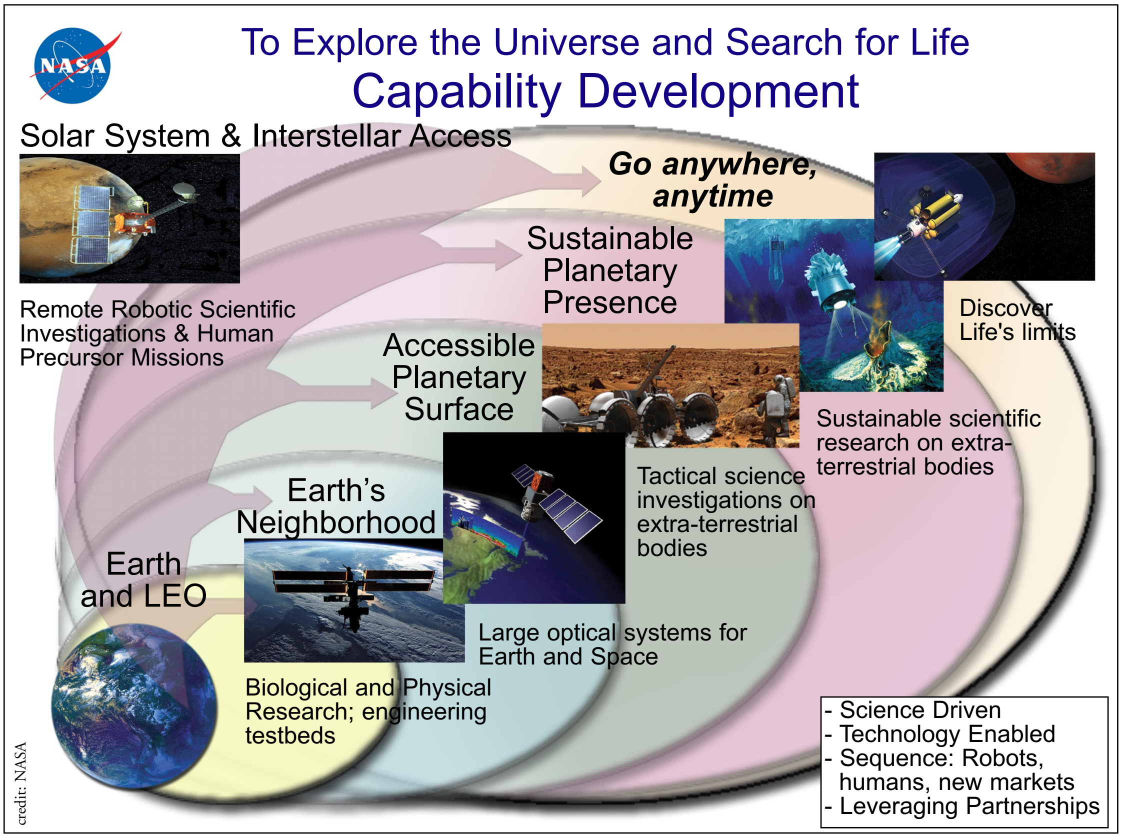


NASA has established stepping stones that represent its ideas for space exploration for the next 25 years. From low Earth orbit (LEO) to Earth's neighborhood (the Moon and stable orbital points out to about 1,500,000 km, or about 932,000 miles) to other planets, humans will eventually go anywhere, anytime.

Research Priorities *continued from page 11*

example is the "Countdown to Launch" event held on June 25, 2002. This event highlighted hands-on education outreach activities that featured actual experiments that flew aboard STS-107. Khalid Alshibli, project scientist for the STS-107 Mechanics of Granular Materials (MGM) experiment, displayed the MGM flight hardware and explained the science behind the experiment. Alshibli also wrote classroom activities for middle and high school students that explained the MGM experiments (the activities are available at *http://spacelink.nasa.gov*). Other OBPR researchers have also contributed to developing activities that involve students in their experiments and give them hands-on experience not usually possible in a classroom.

The Internet and multimedia technology provide new possibilities for sharing the excitement of space research. For example, the new Virtual Astronaut web site uses interactive 3-D ISS simulation to integrate life science data, ISS research, and NASA educational products into a suite of instructional materials. Virtual Astronaut (*http://virtualastronaut.jsc.nasa.gov*) allows educators to show middle school students recent findings in physical, space, and life sciences through electronic student activities and as teacher materials.

What's Next?

If OBPR is to inspire the next generation to reach for their dreams in space, it must first lay the groundwork to enable that generation to do more than dream. The OBPR Research Plan includes a section that describes the steps humans will need to take to build on the legacy of the Apollo program beyond low Earth orbit. Another group, led by NASA Space Architect Gary Martin, has the task and privilege of looking to the distant horizon and determining what it will take for humankind to make the next big leap.

Martin's team has developed a 25-year strategy to get humans from Earth and low Earth orbit all the way to the ability to travel "anywhere, anytime." The OBPR Research Plan outlines the "stepping stones." The first step is low Earth orbit, where the ISS orbits. The next steps are traveling to Earth's neighborhood (including the Moon), then touching down on accessible planetary surfaces, then establishing a sustainable permanent presence on other planets, and finally acquiring the ability to travel throughout the entire Solar System.

The year 2003 marks the 42nd year of the space program. In that time, humankind has seen space exploration and research grow from a dream to a very real and ongoing opportunity. NASA scientists have gone from using 2-second experiments in drop towers to 2- to 6-month experiments on the ISS. However, there is much left to learn. Using tools such as OBPR's five organizing questions will help ensure that resources will be put to the best possible use as NASA continues to explore and expand human knowledge of the Earth and beyond. In the words of the Chinese proverb, "A journey of a thousand miles begins with a single step." Humans are a few steps into the grand journey into space, but there are many miles yet to go.

Carolyn Carter Snare

Further information about the ReMAP task force and the OBPR Research Plan is available at *http://spaceresearch.nasa.gov/general_info/ReMAP.html* and *http://spaceresearch.nasa.gov/research_projects/resplans.html*, respectively. The International Space Station Management and Cost Evaluation task force is discussed in a press release available at *http://spaceresearch.nasa.gov/general_info/prespublic.html*.

Great things *continued from page 13*

Chutjian and his team have published several papers on their work:

Chutjian, A., et al. (2000). A miniature quadrupole mass spectrometer array and GC for spaceflight: astronaut EVA and cabin-air monitoring. *SAE Technical Paper Series 2000-01-2300.*

Orient, O.J., and Chutjian, A. (2002). A compact, high-resolution Paul ion trap mass spectrometer with electron-impact ionization. *Rev. Sci. Instr.* 73, 2157.

Orient, O.J., Chutjian, A., and Garkanian, V. (1997). Miniature, high-resolution quadrupole mass spectrometer array. *Rev. Sci. Instr.*, 68, 1393.

Garden *continued from page 15*

using the least power and volume. Lessons we've learned are directly applicable to the controlled-environment and agriculture industries. And that efficiency relates to income," Stutte concludes. "This technology can be adapted to conserving water, minimizing waste, and stretching resources between competing urban and agricultural interests."

That's a lot of progress for a little salad.

Julie K. Poudrier

For more information on Stutte's research, visit *http://spaceresearch.nasa.gov/research_projects/ros/bpspesto.html.*

Tiny Bubbles *continued from page 17*

For OBPR Research Task Book descriptions of Dhir's two investigations, see *http://research.hq.nasa.gov/taskbook/tb2001/search/retrieve_task.cfm?task_id=352* and *http://research.hq.nasa.gov/taskbook/tb2001/search/retrieve_task.cfm?task_id=1125.*

Sending students *continued from page 21*

classmate. "After participating in SLSTP, I had a general feel about NASA, space life sciences, and the opportunities that were available in space flight research," Bateman says. "I also realized that, one way or another, I wanted to do something that involved space research."

Bateman's next space experience came a couple years later in his hometown of Fort Collins, Colorado, where he was a graduate student in solid mechanics and structural engineering at Colorado State University (CSU). In the summer of 1993, the American Institute of Aeronautics and Astronautics held a student conference at CSU, at which Bateman spoke about his SLSTP experiences with student interns from BioServe Space Technologies, a NASA Commercial Space Center jointly located at the University of Colorado and Kansas State University.

"I was impressed with the direct access BioServe had to space," Bateman says. "BioServe was actually flying experiments." (BioServe Space Technologies specializes in life science research and spaceflight hardware design for biomedicine, biotechnology, and agriculture.) Intrigued, Bateman applied for a BioServe internship that let him not only participate in flight experiments but also write and publish experimental results and serve as a student co-investigator on investigations that flew on space shuttle missions STS-69 and STS-73.

credit: NASA

Ted Bateman, a former intern in NASA's Space Flight and Life Sciences Training Prgram, and the landing team wait for the return of the Commercial Biomedical Testing Module on board flight STS-108, December 17, 2001. Bateman is standing in front, wearing a purple shirt and blue jeans.

Funded by a NASA Graduate Student Research Program Fellowship from Ames Research Center (Moffett Field, California), Bateman completed a doctoral degree in bioengineering from the University of Colorado, Boulder in 1999. Currently an assistant professor in the Bioengineering Department at Clemson University Clemson in South Carolina, Bateman continues the research in bone and protein treatments that he began toward the end of his term at BioServe. With his background in physics, structural engineering, and bioengineering, it is small wonder that Bateman ended up in bone research. "Bone work was the most logical place for me to be," he says. "As a hard tissue, bone provides many structural functions for the body."

Spurring their interest and enriching their minds, NASA's internships provide a wealth of opportunities for undergraduates and graduate students and inspire their career choices in science, mathematics, and engineering disciplines.

Chris McLemore

For more information about NASA research opportunities, go to *http://education.nasa.gov.* For information about the Spaceflight Life Sciences Training Program, go to *http://www-pao.ksc.nasa.gov/kscpao/educate/slstp.htm.*

***Satellite** continued from page 19*

antennas steer beams electronically, enabling high data rate communication between a satellite and a ground mobile unit. Laser communication systems can handle very high data rates and selectively communicate with specific points on Earth. Both phased array antennas and laser communication systems can transmit huge quantities of information. The difference lies in each one's mode of communication. The phased array antenna steers Ka-band radio waves to its receiver, and laser communication units manipulate light to transfer information.

One of the purposes of the payload is to "test the effectiveness of phased-array antennas in LEO," says Boyle, "where at certain times the signal will be cutting through a lot more of the atmosphere, depending on the angle of the beam." While a phased-array antenna would have a superb connection when directly above (and closest in its orbital path to) its receiver on the ground, researchers need to understand how a longer path and possible rain interference may affect the space-to-ground connection of a phased-array antenna in LEO. "Phased-array antennas allow for higher data transmission rates at reduced power," says Boyle. "The signal can be steered across the horizon, providing a longer connection between the ISS and the ground station." From this research, industrial partners expect products such as low-cost broadband phased-array technologies for small satellites applicable to space- and ground-based networks.

The payload also will test the effectiveness of laser systems in LEO. "Industries have already demonstrated broadband antennas in GEO," says Boyle. But laser beams might offer a high bandwidth of more than 600 Mbps, which would open a host of remote sensing and communications applications. For example, a boost in small satellite systems would give meteorologists a true up-to-the-minute scoop on the weather and cable service an increase in performance.

Increased bandwidth also would greatly benefit NASA's space communications network. For example, an upgrade on its satellite downlink could significantly improve tele-science opportunities, the communication between principal investigators and their experiments on the ISS, as well as the payload specialists running the experiments. High-bandwidth technology would also enable deep space probes to send higher data rates back to Earth.

The other four payloads proposed for the EXPRESS pallet seek to study spacecraft technology components that could enhance power, propulsion, life support, and cooling systems for long-duration spaceflight missions.

Future Possibilities

The type of advanced technology industry might test on the EXPRESS pallets could lead to products that would improve the surveillance of enemies, enable the transfer of real-time video around Earth (and perhaps beyond), and assist scientific exploration by deep space probes. Thus, Boyle foresees that advances in commercial spacecraft technology, courtesy of testing on the EXPRESS pallets, could have many ripple benefits for applications both on Earth and in space.

"The remote sensing and communication technology experiments planned for the first ExP are primarily to help commercial industry validate these advanced technologies for building better satellites focused on serving people on Earth," says Boyle. "That's a good thing."

"But," he continues, "we believe that in the near future there's going to be activity in space, such as having satellites serviced, refueled, or repaired remotely. And there will be space tourism." For such new activities to become reality, much technology will have to be developed and tested in the environment of low Earth orbit.

Boyle predicts the ISS will prove key: "We think the space station will continue to fulfill that very good role as a technology test bed out into the future when all kinds of stuff that people had previously only imagined would happen in space actually does."

Chris McLemore

For more information about CSCE and commercial spacecraft technology, go to *http://engineer.tamu.edu/tees/csce.*

***Meetings** continued from page 23*

Microgravity Transport Processes in Fluid, Thermal, Biological, and Materials Sciences Conference III

Davos, Switzerland
September 14–19, 2003
http://www.engconfintl.org/3aubody.html

This year's international conference will provide the opportunity for researchers from the various transport fields to gather and exchange ideas and information. Organized by the United Engineering Foundation, the conference will include papers and presentations on boiling phenomena, biotransport processes, acoustic levitation studies, and materials processing as related to microgravity.

EDUCATION

24th Annual National Educational Computing Conference

Seattle, Washington
June 30–July 2, 2003
http://www.neccsite.org/

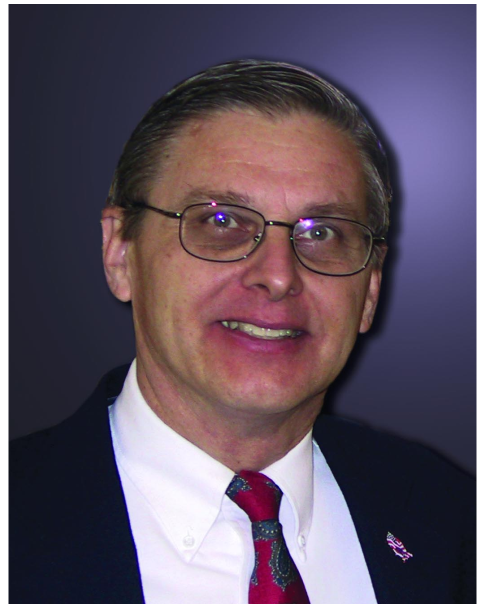
Presented by the International Society for Technology in Education, this year's National Educational Computing Conference (NECC) has the theme "Visions and Reflections." The conference will focus on changes in technology and the need of educators to stay current and take advantage of these changes to better teach their students. Events at the conference will include exhibits; presentations; workshops; and keynote, breakout, and special interest sessions.

PROGRAM RESOURCES

Office of Biological and Physical Research
http://spaceresearch.nasa.gov
Science Program Projects
http://research.hq.nasa.gov/taskbook.cfm
Commercial Projects
http://cscsourcebook.nasa.gov
Space Life Sciences Research Resources (for literature searches)
http://spaceline.usuhs.mil/home/newsearch.html

Profile: Joseph Santner

As director of research of the American Foundry Society, Joseph Santner helps to implement the vision of the metal casting industry to expand the already wide range of uses for metal castings — from consumer goods to spacecraft engines and beyond.



credit: American Foundry Society

What does the ancient art of metal casting have to do with the 21st century high-tech science of spacecraft? Plenty. Metal castings are among the crucial components of spacecraft, including components of the space shuttle's main engine high-pressure turbo pump and single-crystal blades.

Developing and disseminating knowledge on metal casting technology is the mission of Joseph Santner, director of research for the American Foundry Society (AFS), a cofounder with NASA and Auburn University (Auburn, Alabama) of the Solidification Design Center, one of NASA's commercial space centers.

Metal castings appear in thousands of products — from plumbing fixtures to appliances, power tools to the space shuttle. Although ubiquitous in the 21st century, metal castings are produced by an ancient process in which molten metal is poured into a mold and allowed to solidify. It is then removed for use, generally as part of a larger assembly.

Although the basic technology dates back some 5,000 years, metal casting is not what it used to be. "Until the mid-20th century," Santner says, "metal casting was an art, not a science." Today, the science of metal casting is precise and complex, requiring a thorough understanding of the physics and chemistry of every engineering alloy and molding material used in the process.

Early in his career, as a materials development engineer at the Air Force Materials Development Laboratory at Wright-Patterson Air Force Base in Ohio, Santner realized that information on the characteristics of engineering metals was vital not only to the aerospace industry but to many other manufacturing industries as well. So gathering and disseminating data on metals and metal alloys became his passion. For more than a decade, he worked on characterizing the properties of metal composites and helping small businesses with innovative research to develop the economical processing of metal composite materials into structural shapes. These experiences gave him insight into the needs and capabilities of hundreds of foundries operating in the United States, the majority of which are small businesses. By the time he became the AFS's director of research in 1995, he had clear ideas on how foundries could position themselves to provide needed high-tech castings to industry. By 1996, Santner also saw how becoming an industrial partner in NASA's Solidification Design Center (SDC) at Auburn University would be valuable for both the AFS and NASA.

Today, Santner considers the AFS the authoritative source for the latest information on engineering alloys and molding materials for high-tech castings, and the AFS has teamed with the SDC to make this information available to researchers around the world. Engineers at Auburn maintain a database of the SDC's findings about the characteristics of various engineering alloys and molding materials under widely differing physical conditions, including the moisture content of sand cooling, the rate of solidification of molten metal, and the effect of gravity on the chemical segregation of different elements within a molten alloy. Researchers at the SDC are providing foundries with basic scientific data and are refining physics-based models to allow computers to accurately predict how a metal will solidify as it cools under various temperatures, pressures, and gravitational fields.

"The devil is in the details," says Santner. "The larger and more complex the desired casting, the more metal casters need to know about how alloys will behave. And if you've got bad data, you can't possibly make good predictions."

Santner's other mission at the AFS is increasing the awareness of foundry technology among current generations of engineers. "In the 1920s and 1930s, most engineering schools taught metal casting technology," he says, but that's no longer the case. "What we need to do is to put metal casting back into the engineer's toolbox. It's a viable way to manufacture components, with real economic payback."

Using the latest computer design tools and inputting accurate information on specific alloys and correct process models, foundries can provide customers with custom-made components, saving time and money in production and producing components of higher reliability. That, in turn, results in better, less expensive products — from blenders to dishwashers to automobiles — for the consumer. "Metal casting," says Santner, "makes it affordable for the common man to live like a king."

By increasing the availability of data on engineering alloys and molding materials, Santner is confident that the metal casting industry will be poised to answer the call for highly specialized, reliable, cost-efficient components. "As the requirements for metal castings have changed," he says, "the inventiveness of metal casters has seen no limits. If you have a requirement, they can figure out how to meet it."

Jacqueline Freeman-Hathaway

Visit the American Foundry Society website at *http://afsinc.org* and Auburn University's database at *http://metalcasting.auburn.edu*. For information on the effects of gravity on metal castings, visit *http://metalcasting.auburn.edu/GravEffects.html*.

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Space Administration

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